EXHIBIT 7

US006757602B2

(12) **United States Patent**
Breed et al.

(10) **Patent No.: US 6,757,602 B2**
(45) **Date of Patent: Jun. 29, 2004**

(54) **SYSTEM FOR DETERMINING THE OCCUPANCY STATE OF A SEAT IN A VEHICLE AND CONTROLLING A COMPONENT BASED THEREON**

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(73) Assignee: **Automotive Technologies International, Inc.**, Denville, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 29 days.

(21) Appl. No.: **10/234,436**

(22) Filed: **Sep. 3, 2002**

(65) **Prior Publication Data**

US 2003/0036835 A1 Feb. 20, 2003

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/853,118, filed on May 10, 2001, now Pat. No. 6,445,988, which is a continuation-in-part of application No. 09/382,406, filed on Aug. 24, 1999, now Pat. No. 6,529,809, which is a continuation-in-part of application No. 09/474,147, filed on Dec. 29, 1999, now Pat. No. 6,397,136, which is a continuation-in-part of application No. 08/798,029, filed on Feb. 6, 1997, now abandoned, which is a continuation-in-part of application No. 08/919,823, filed on Aug. 28, 1997, now Pat. No. 5,943,295.

(60) Provisional application No. 60/136,163, filed on May 27, 1999.

(51) **Int. Cl.**[7] **G06F 7/00**

(52) **U.S. Cl.** **701/45**; 180/268; 180/271; 280/735

(58) **Field of Search** 701/45, 46, 47; 180/268, 271, 272, 273; 280/735

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Breed et al.; Audio reception control arrangement and method for a vehicle; U.S. 2001/0038698, Nov. 8, 2001.*

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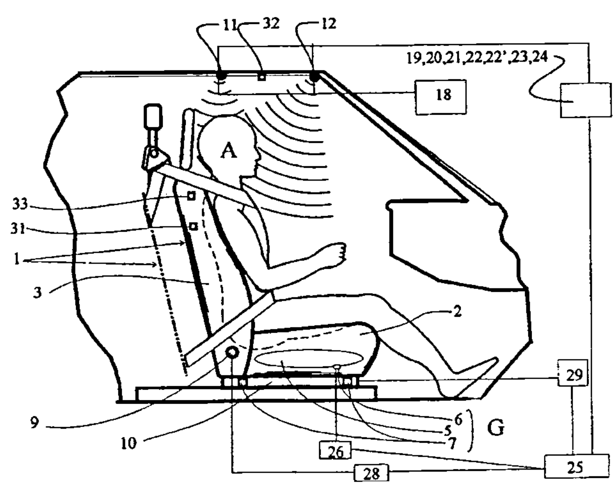
(74) *Attorney, Agent, or Firm*—Brian Roffe

(57) **ABSTRACT**

Method for controlling an occupant protection device in a vehicle in which data is acquired from at least one sensor relating to an occupant in a seat to be protected by the occupant protection device, the type of occupant is classified based on the acquired data and when the occupant is classified as an empty seat or a rear-facing child seat, deployment of the occupant protection device is disabled or adjusted. Otherwise, the size of the occupant is classified based on the acquired data, the position of the occupant is determined by one of a plurality of algorithms selected based on the classified size of the occupant using the acquired data, each algorithm being applicable for a specific size of occupant. Deployment of the occupant protection device is disabled or adjusted when the determined position of the occupant is more likely to result in injury to the occupant if the occupant protection device were to deploy. The algorithms may be pattern recognition algorithms such as neural networks.

56 Claims, 50 Drawing Sheets



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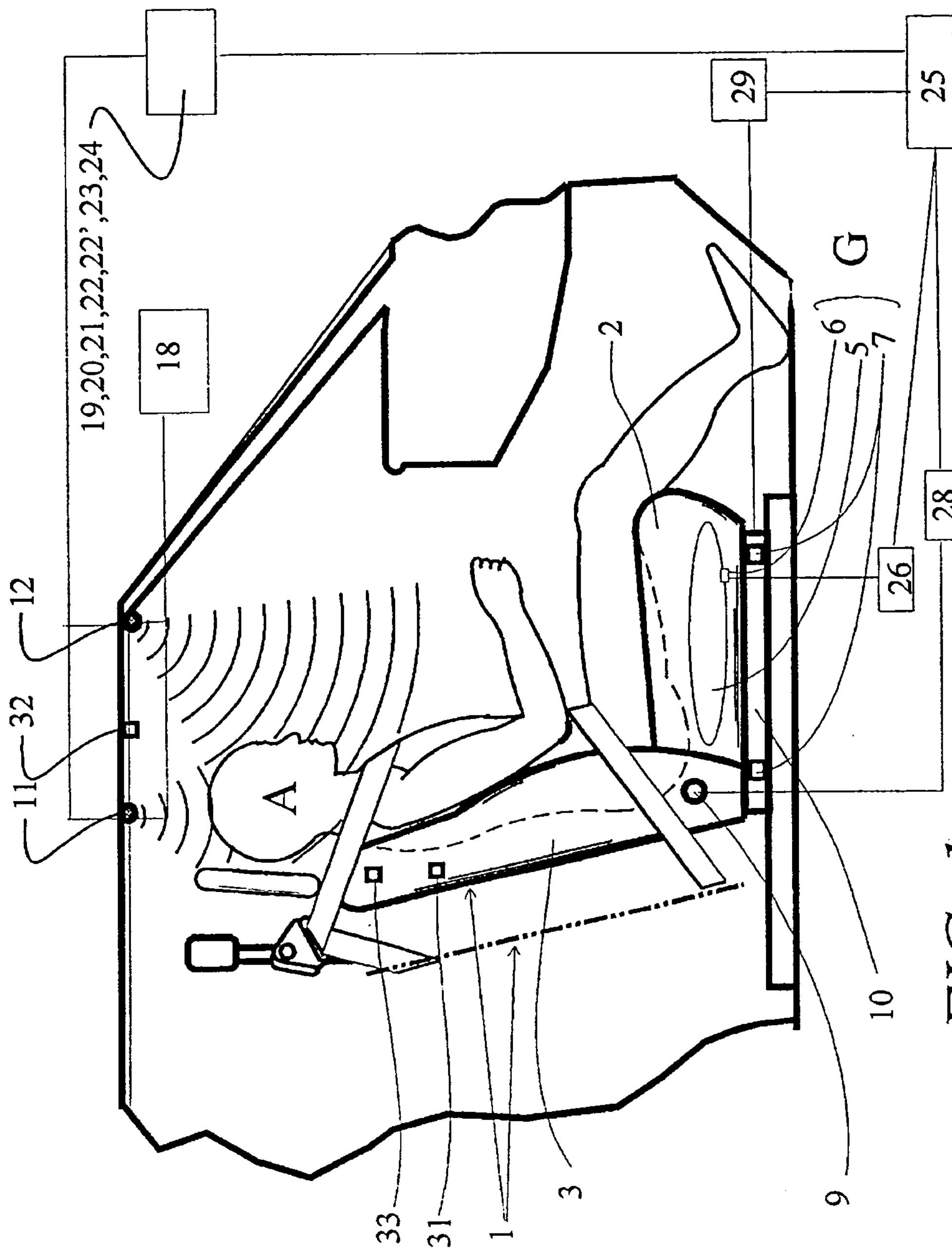

FIG. 1

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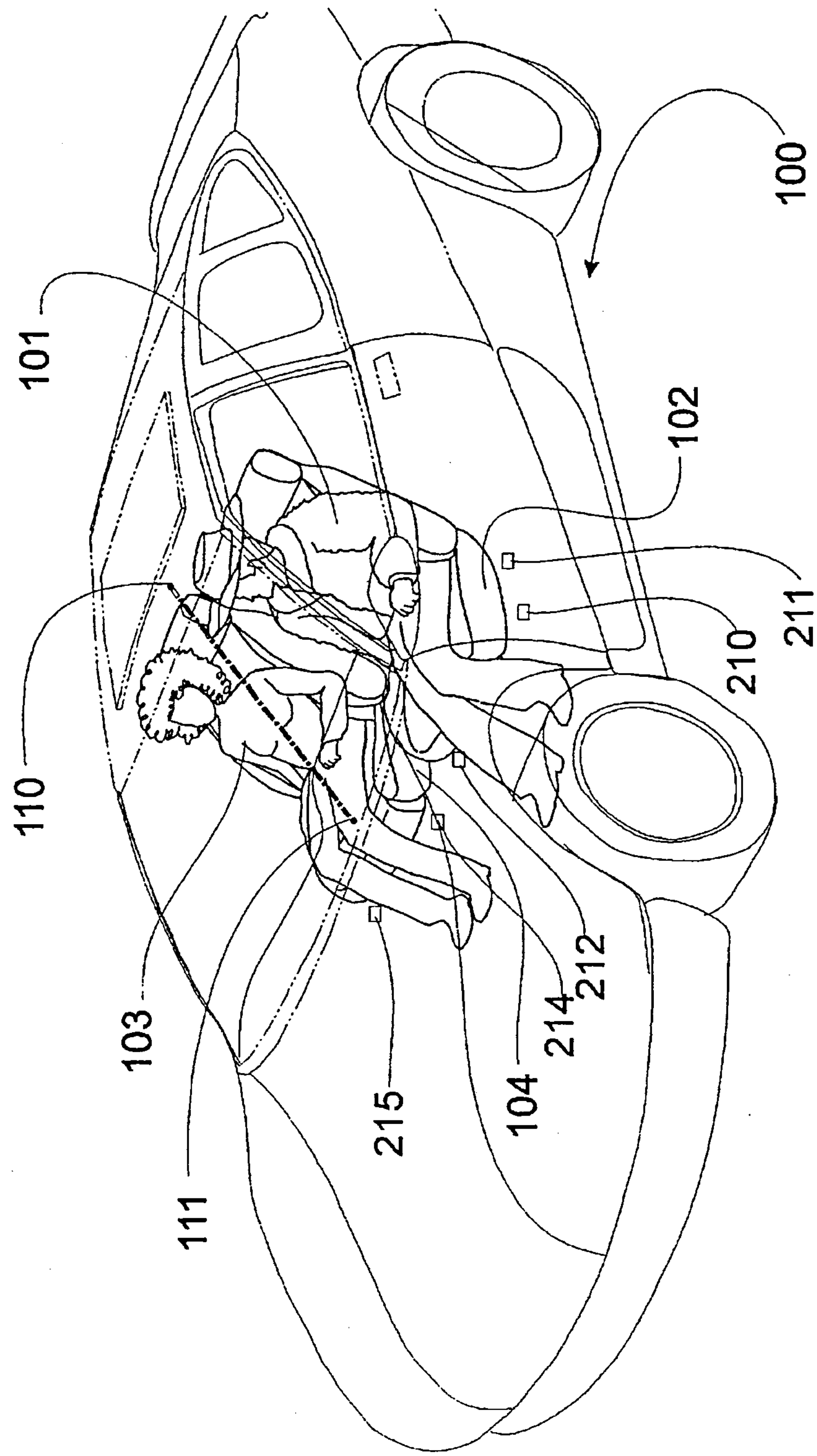

FIG. 2

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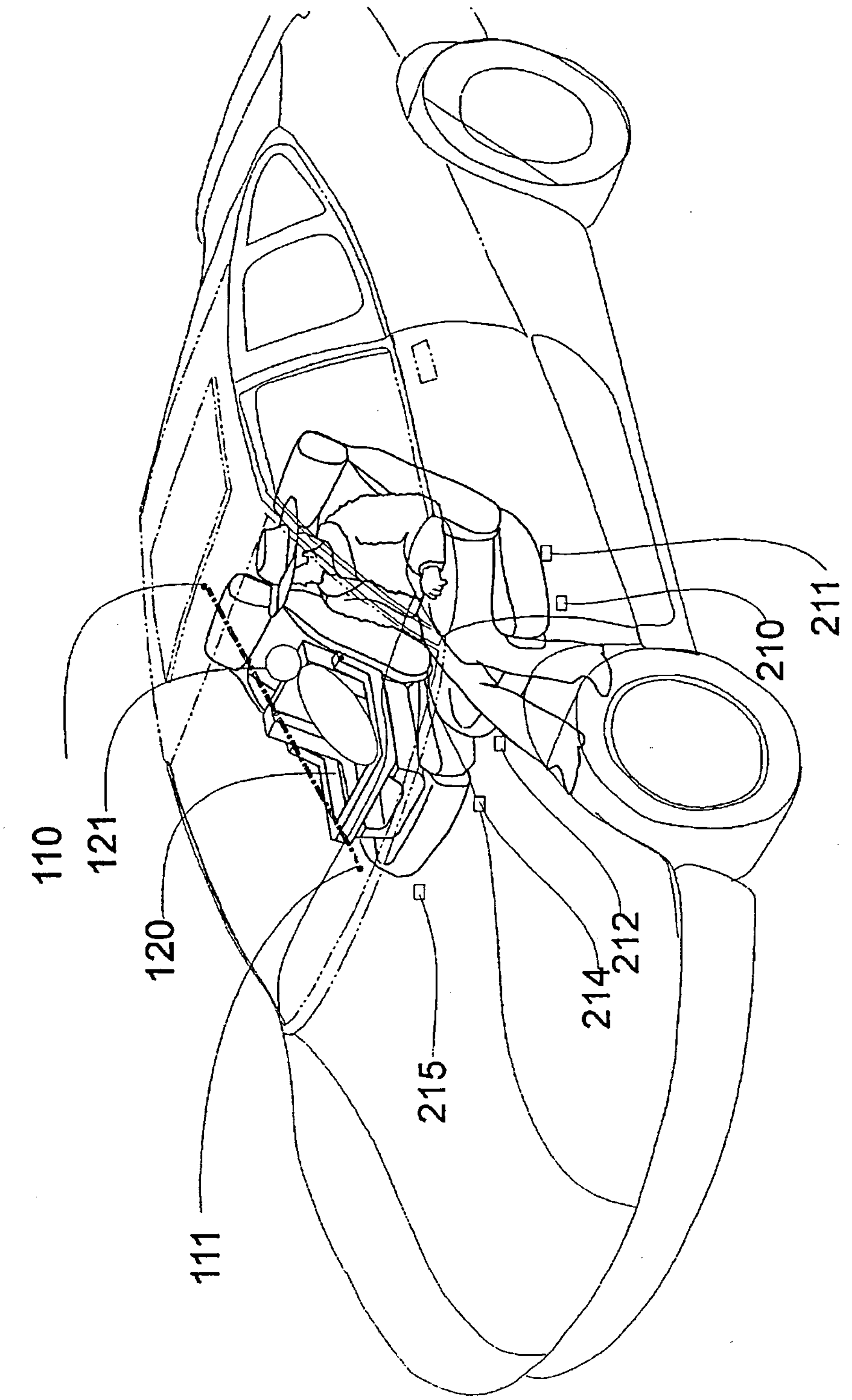

FIG. 3

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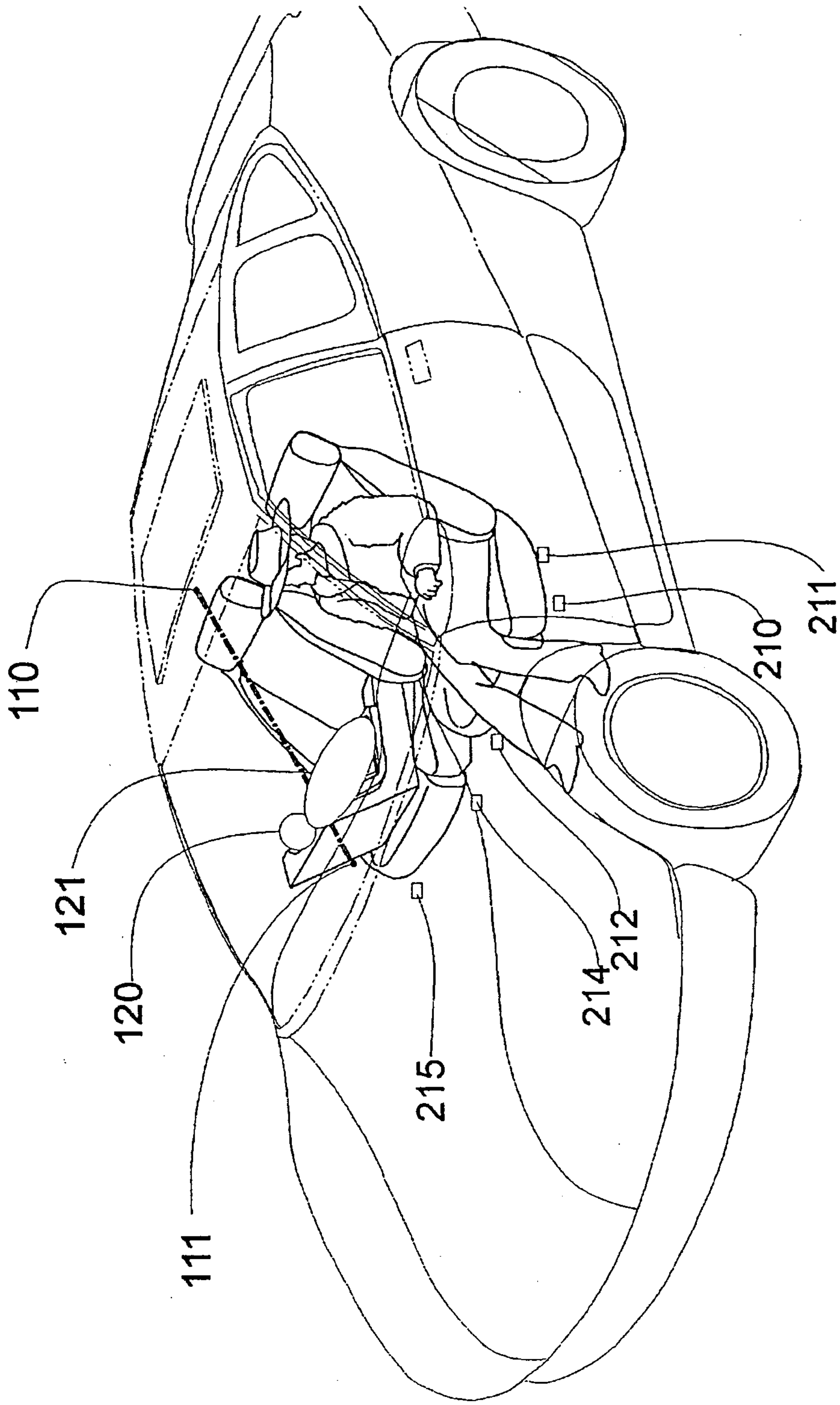

FIG. 4

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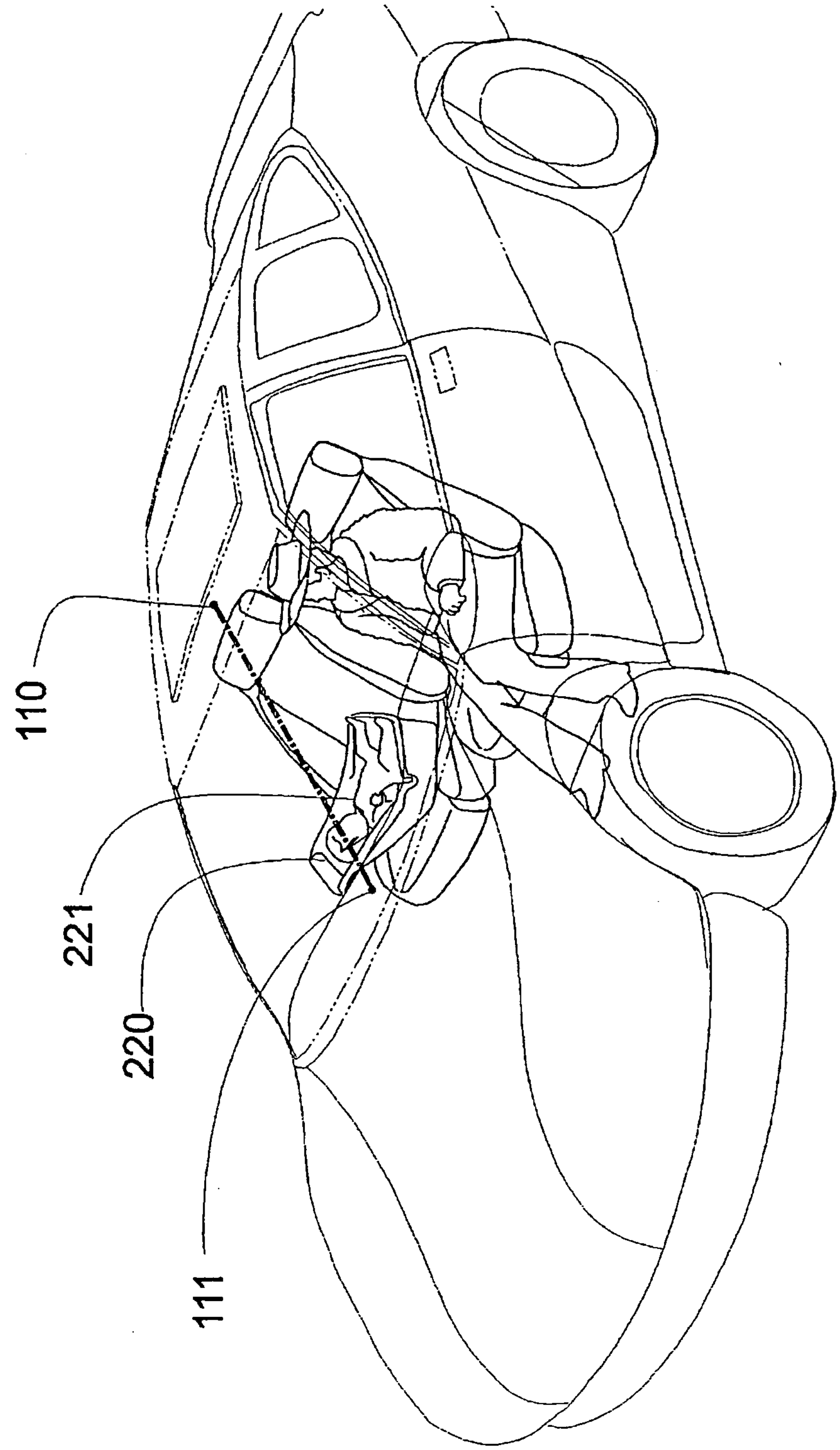

FIG. 5

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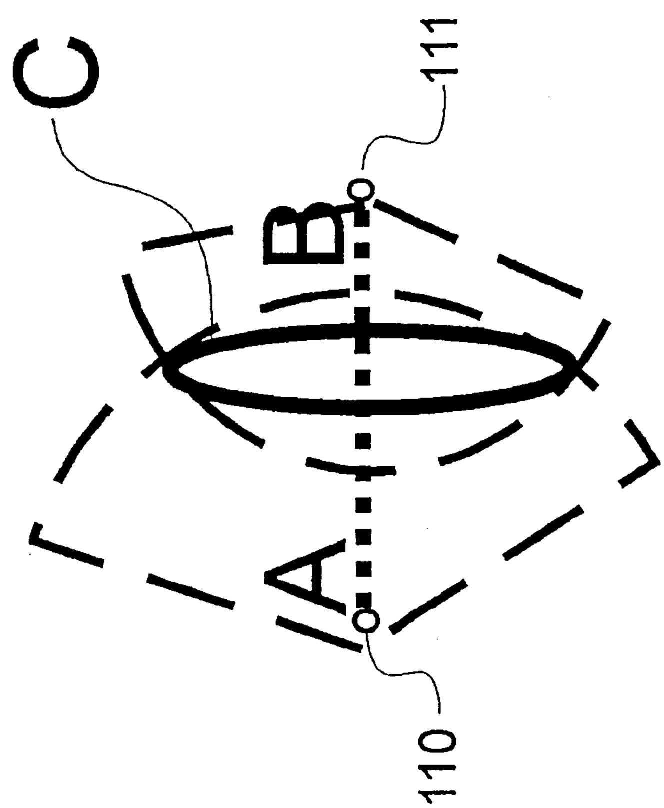

FIG. 6

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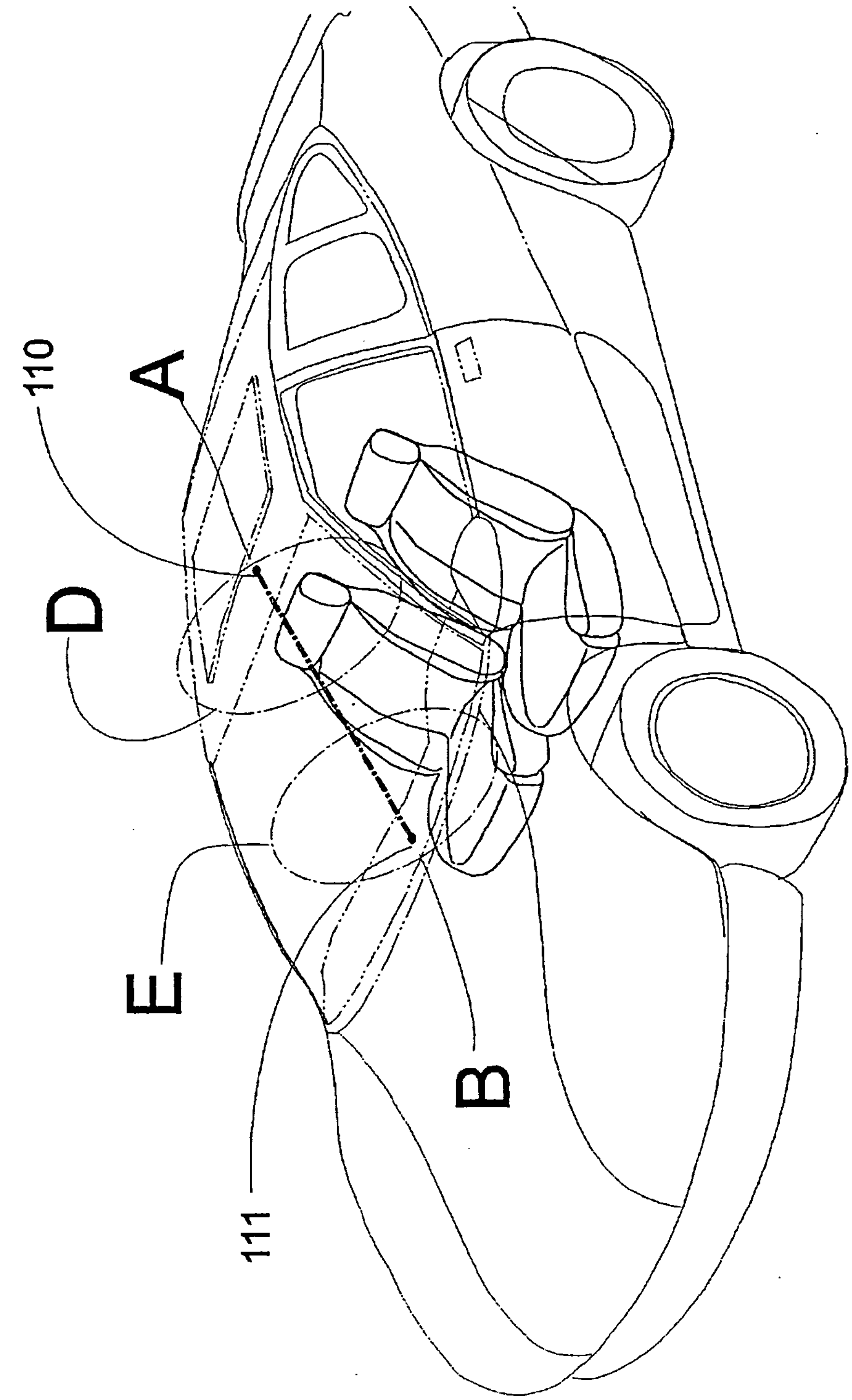

FIG. 7

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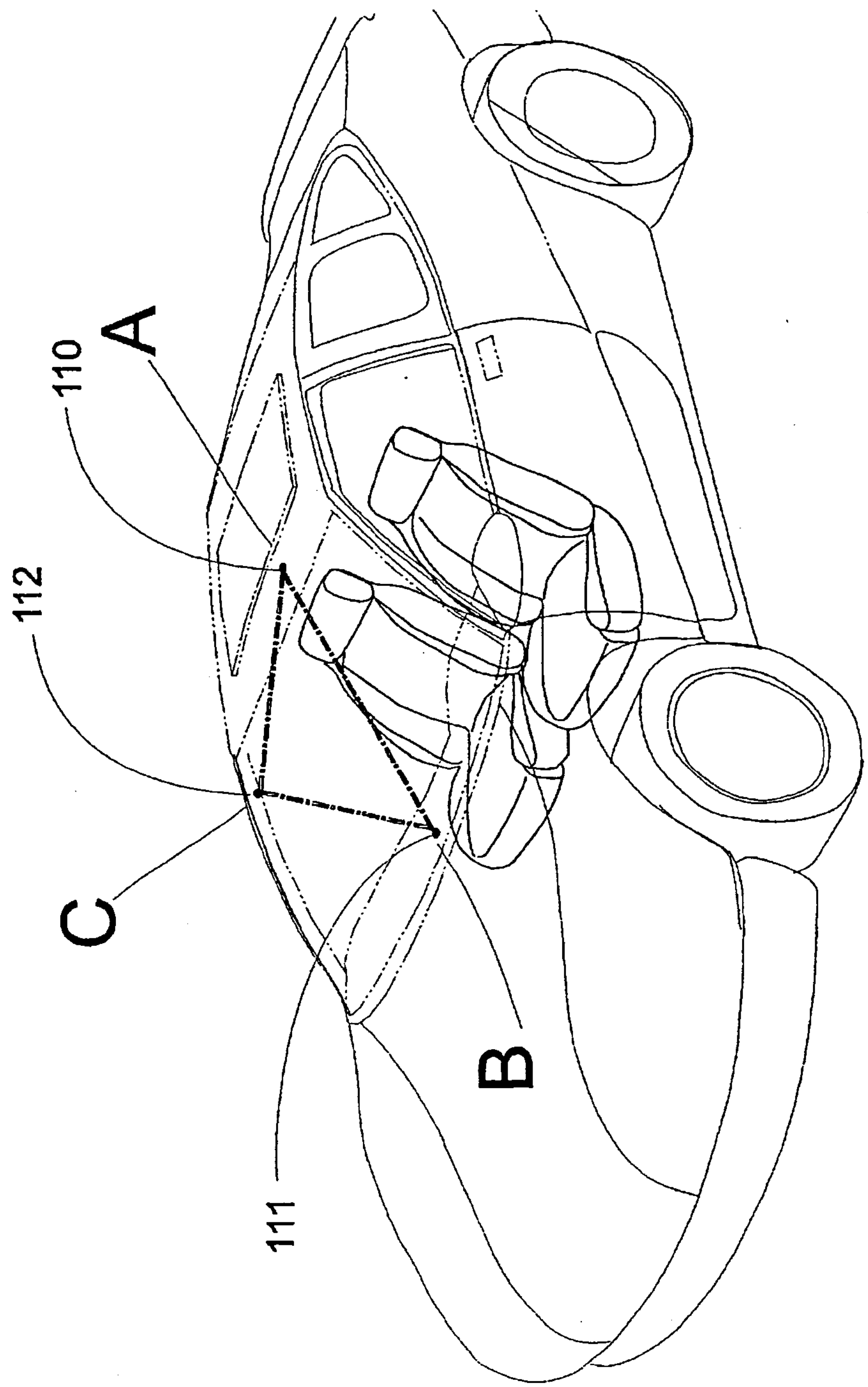

FIG. 8

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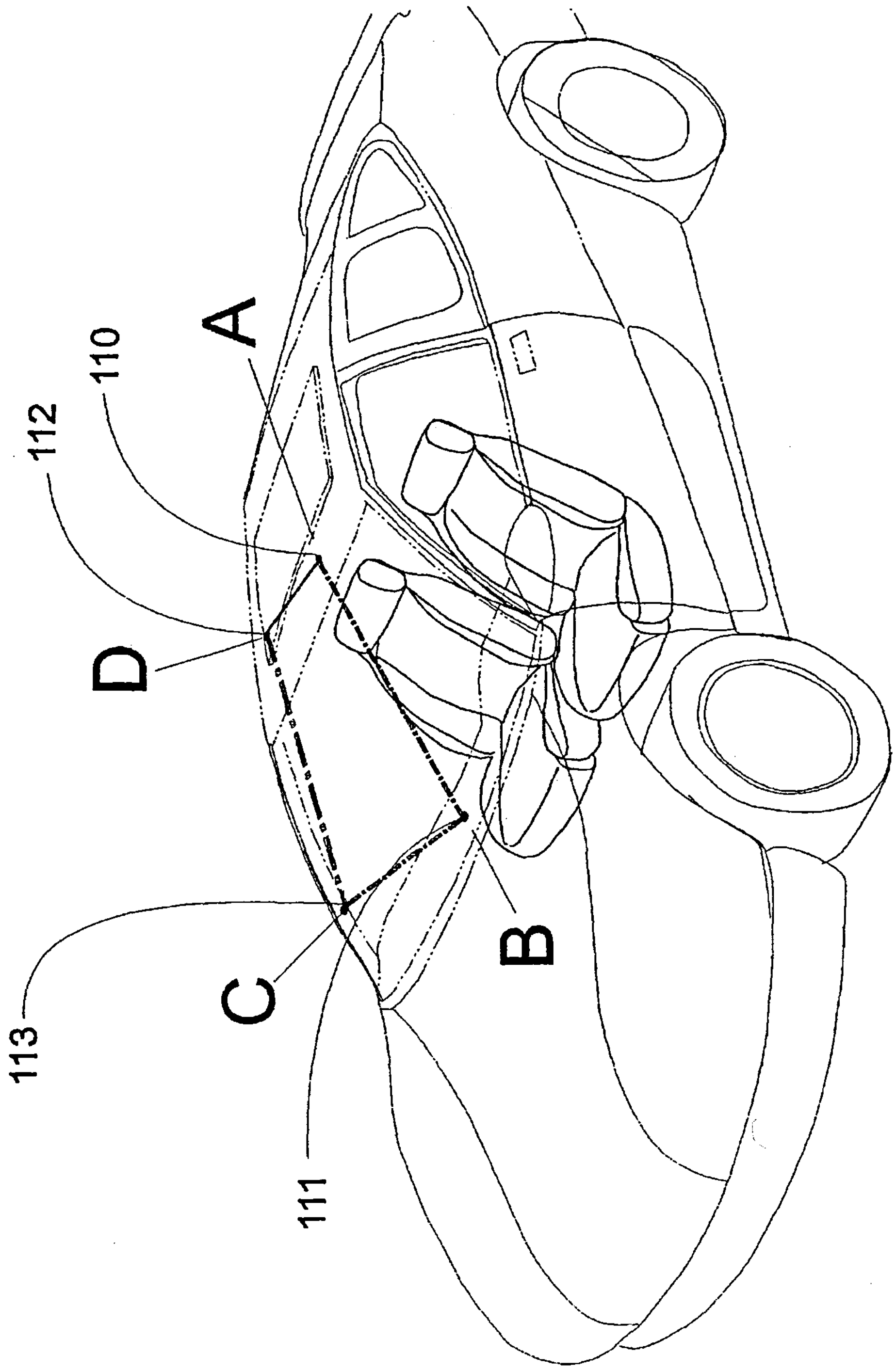

FIG. 9

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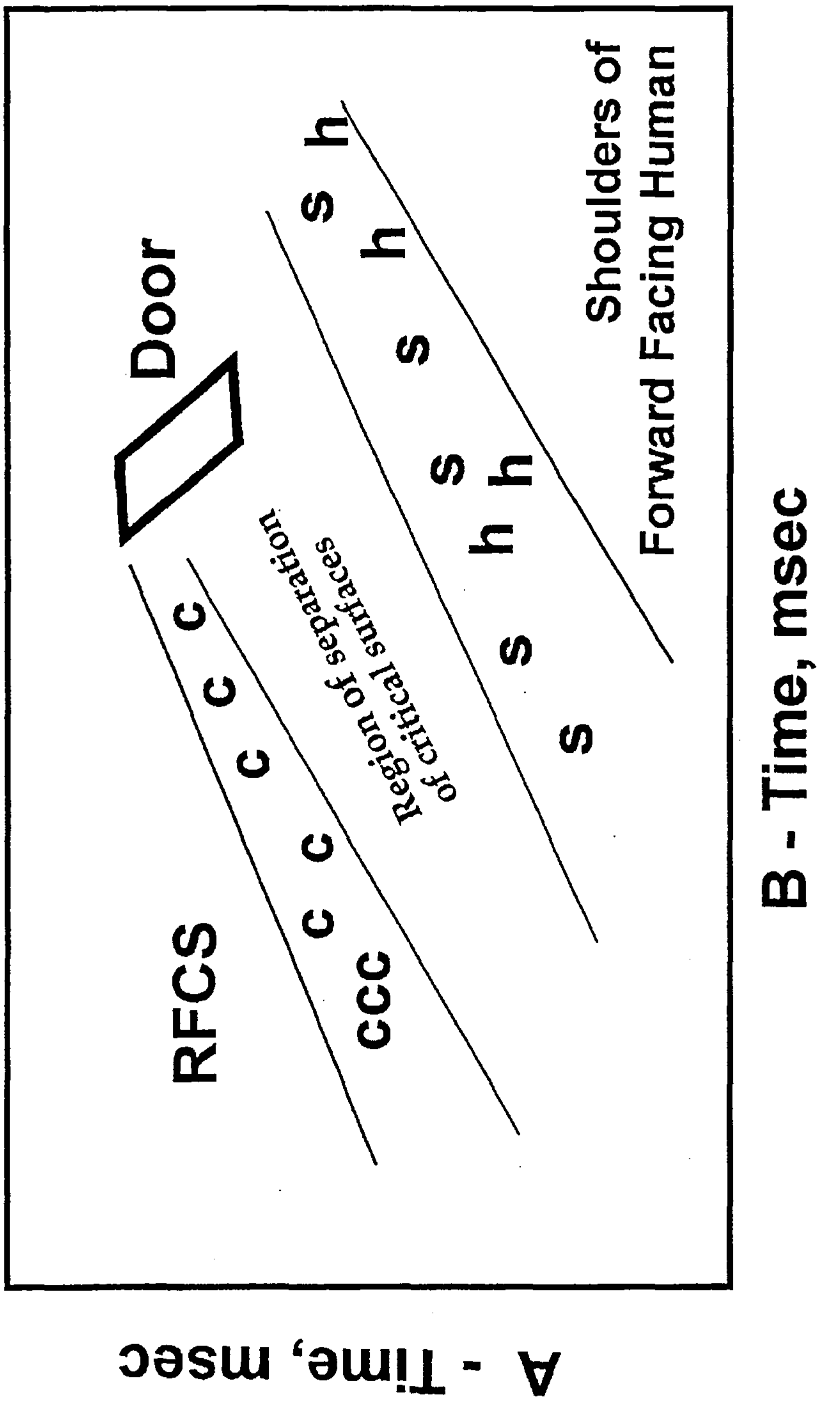
Door
RFCS
c c c c c ccc
Region of separation
of critical surfaces
s h s h s h s h s s
Shoulders of
Forward Facing Human
B - Time, msec
A - Time, msec

FIG. 10

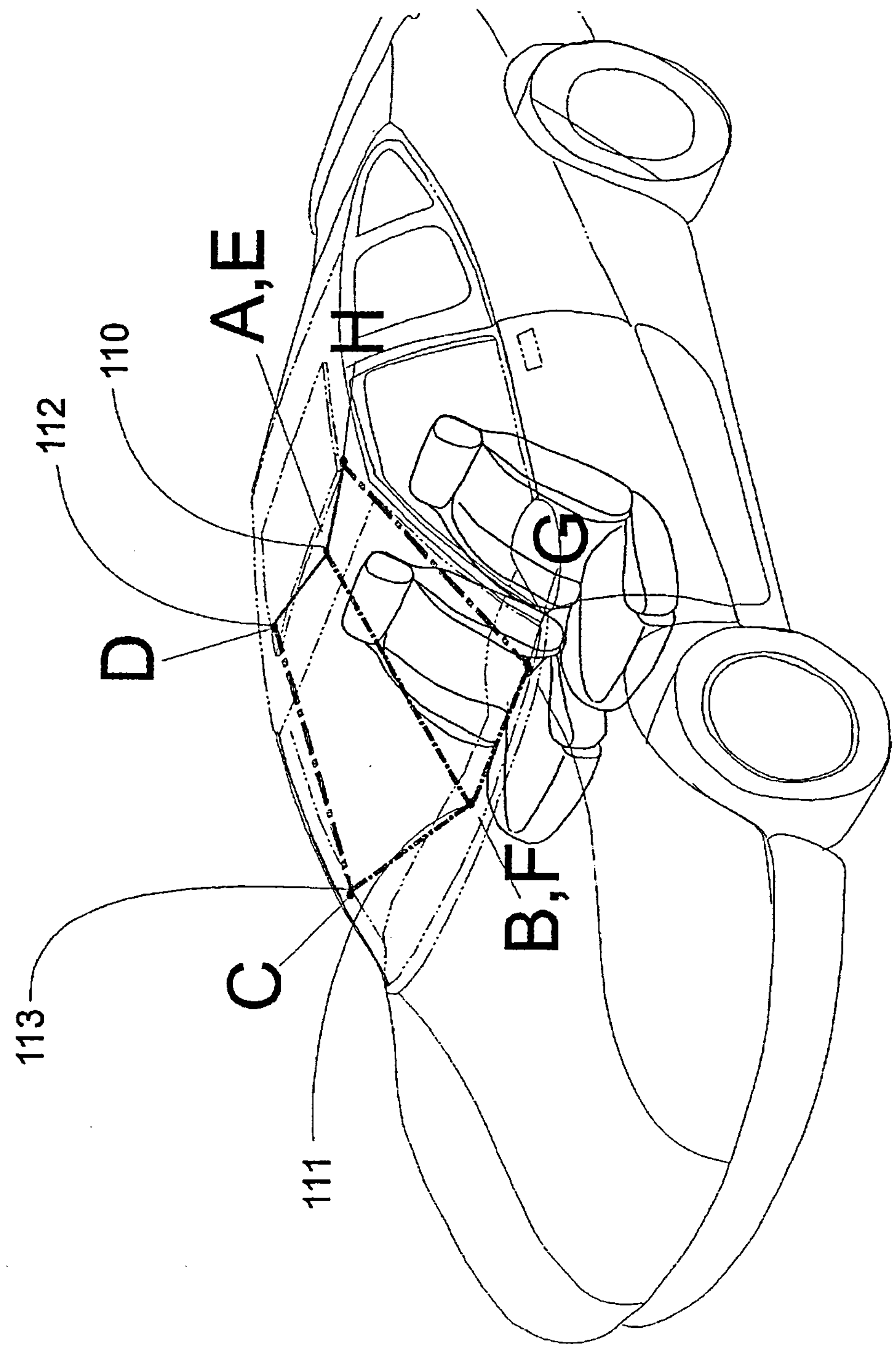

FIG. 11

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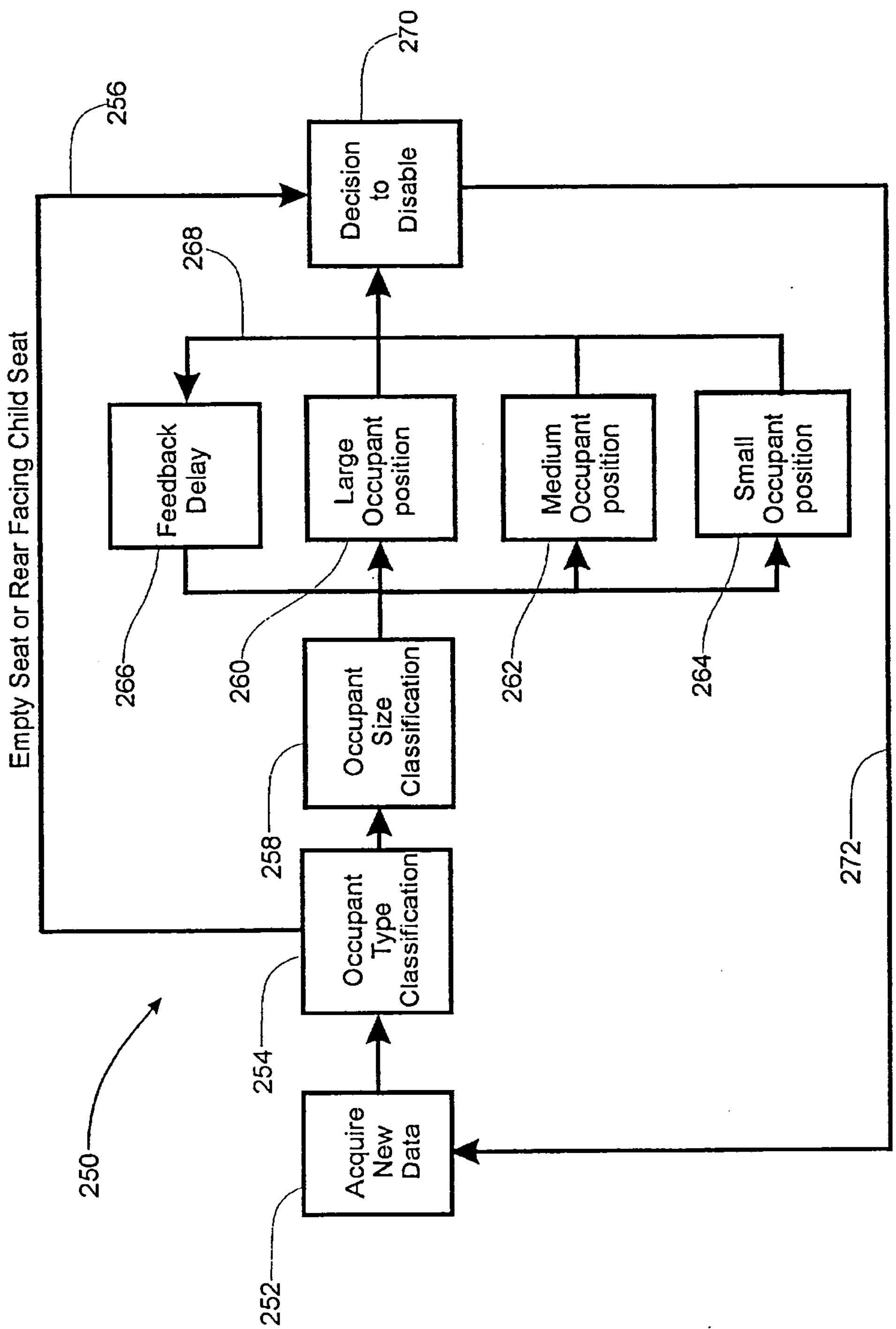

FIG. 12

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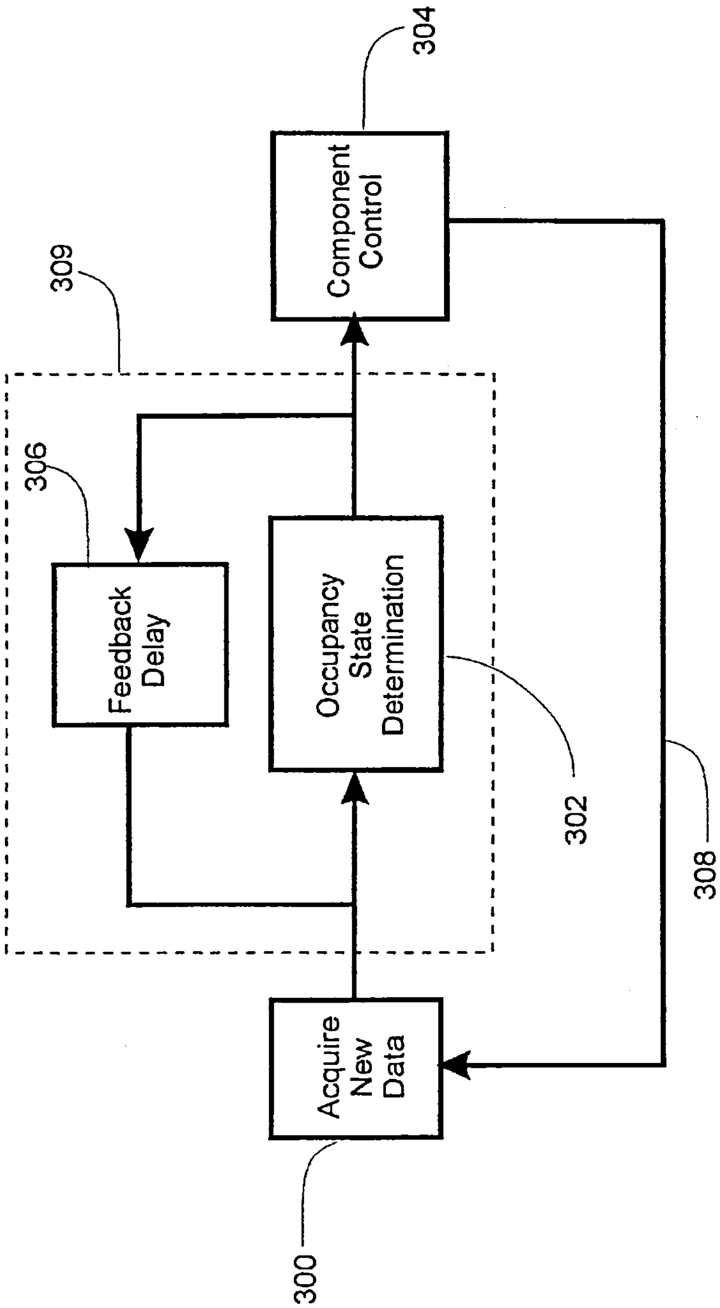

FIG. 13

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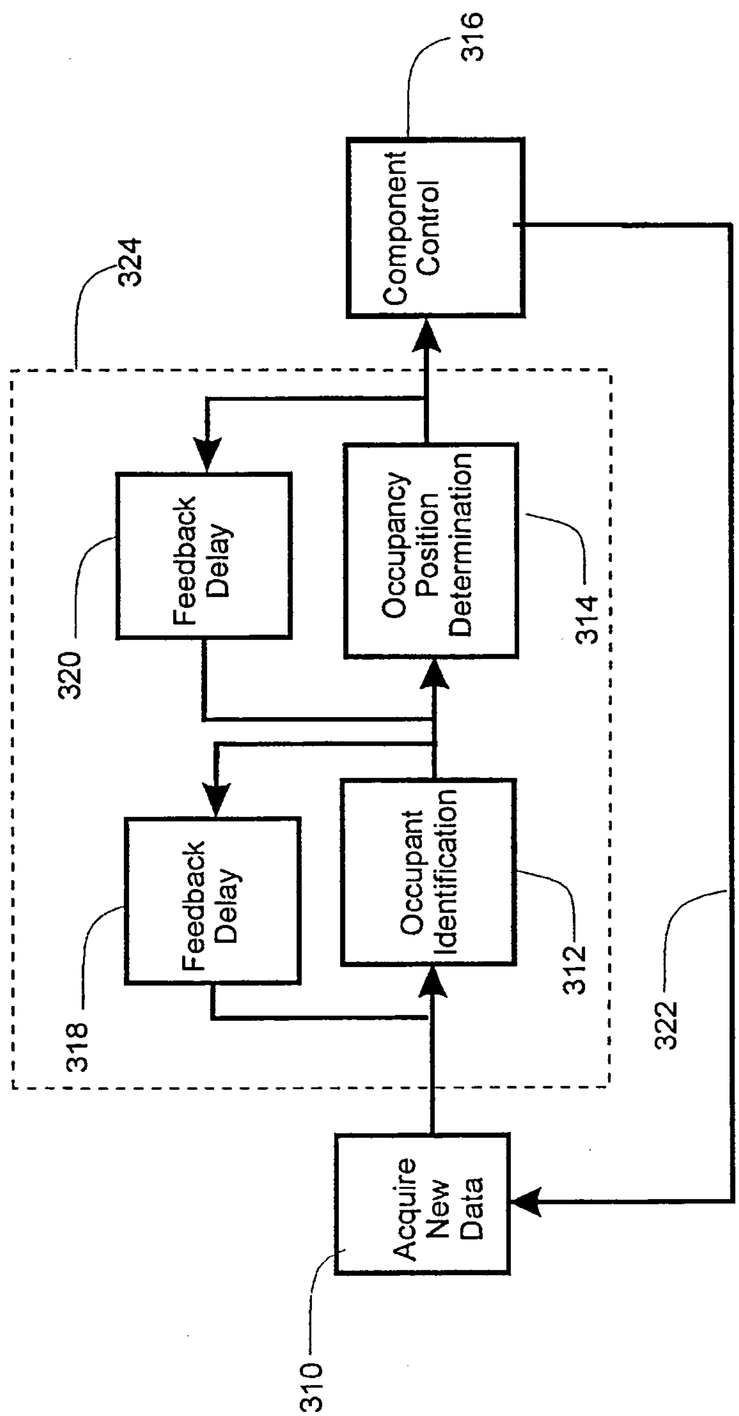
316
Component Control
324
Feedback Delay
320
Occupancy Position Determination
314
Feedback Delay
318
Occupant Identification
312
322
Acquire New Data
310

FIG. 14

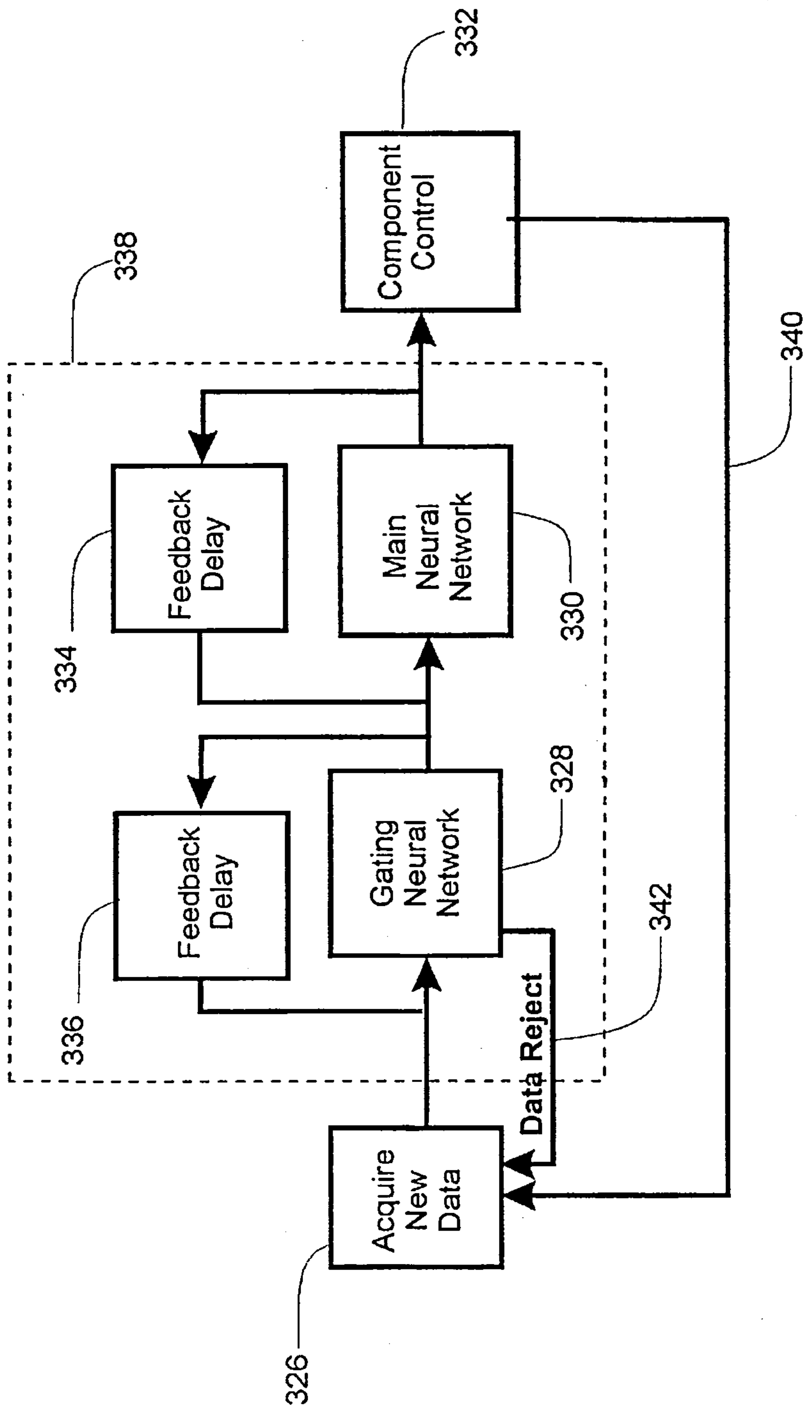

FIG. 15

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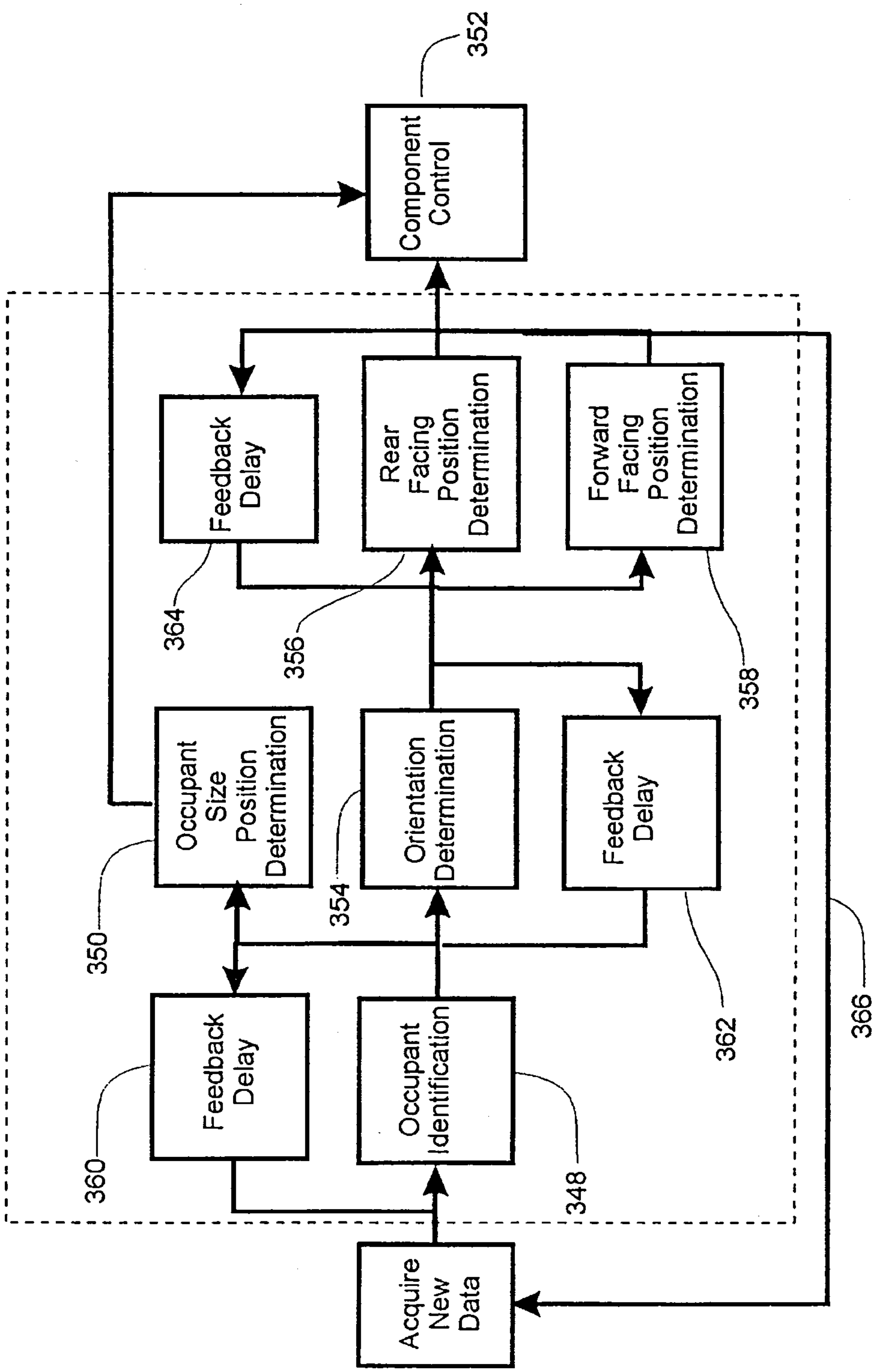

FIG. 16

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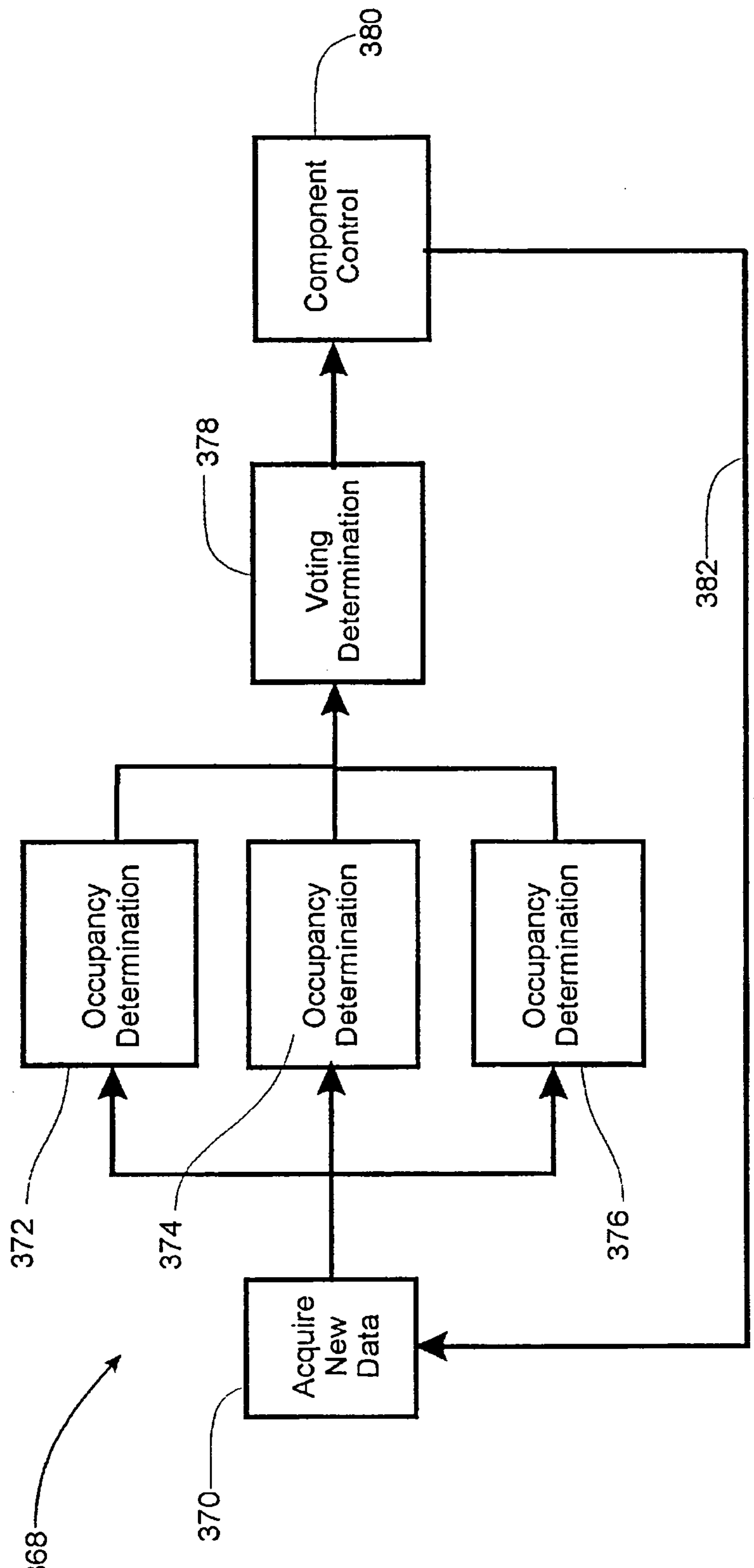

FIG. 17

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Subject Classification

Class	Instances	Weight Category	State
ES	Empty Seat	<10 lb	Empty
FFA	Normally Seated Adult	> 05 lb	Enable
FFC	Normally Seated Child	<10,105> lb	Enable
FFC	Normally Positioned Forward Facing Child Seat	<10,45> lb	Enable
OOP	Out-of-position Adult	>105 lb	Disable
OOP	Out-of-position Child	<105 lb	Disable
OOP	Out-of-position Forward Facing Child Seat	<10,45> lb	Disable
RFS	Rearward Facing Child Seat	<10,45> lb	Disable
RFS	Rearward Facing Infant Seat	<10,45> lb	Disable

FIG. 18

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Categorization of Human Subjects

	Weight Range kg (lb)		Height Range m (in	
Child		<0.95,1 .1 5> (<3'1",3'9">)	<1.10,1.30> (<3'7",4'3">)	<1.25,1.45> (<4'1",4'9">)
	<11,25>(<24,55>)	C11	C12	C13
	<22,36> (<48,79>)	C21	C22	C23
	<33,47> (<73,103>)	C31	C32	C33
Adult		<1 .45, 1 .65> (<49,555')	<1 .60,1 .80> (<53,51 1 '5')	<1 .75, 1 .95> (<59,655')
	<45,70>('<99,154>)	A11	A12	A13
	<65,90> (<143,198>)	A21	A22	A23
	<85,110>(<187,242>)	A31	A32	A33

All Human Subjects are to wear light clothes (typically slacks and T-shirt) on entry.
Other types of clothing to be provided by ATI

Child Surrogates

Doll		Baby=0.50m (approx. 20")	Infant=0.75m (approx. 30")	Child=1.20m (approx. 48")

FIG. 19

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Rearward Facing Infant Seats

Designation	Child Seat	Attributes
Training	Arriva	base, hood
Independent	Assura565	hood
Training	Baby-Safe	-
Training	Century 590	base, hood
Training	Evenflo Discovery	base, Tbar
Training	Evenflo Joyride (new)	hood
Independent	Evenflo Joyride (old)	-
Training	GerryGuard	base
Validation	Kolcraft Travelabout	base, Tbar
Training	Rock-n-Ride	-
Training	TLC	-

FIG. 20

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Rearward Facing Child Seat

Designation	Child Seat	Attributes
Training	Centuryl000	-
Validation	Century 2000 STE	-
Training	CenturyOvation	-
Training	Century Smartmove 5T	table
Training	Champion	table
Training	Fisher Price Child Seat	table
Training	Touriva	-
Training	Ultara	table
Training	Vario Exclusive	table

FIG. 21

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Forward Facing Child and Booster Seats

Designation	Child Seat	Attributes
Training	Centuryl000	-
Validation	Century 2000 STE	-
Training	CenturyOvation	-
Validation	Century Smartmove 5T	table
Training	Champion	table
Validation	Fisher Price Booster	-
Training	Fisher Price Child Seat	table
Training	Gerry Booster	table
Training	Touriva	-
Training	Ultara	table
Training	Vario Exclusiv	table

FIG. 22

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Vehicle Configuration Series

Con fig	Seat Track (+/1 .05")										Seatback Recline (+/- 2°)										Windows									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
A	0	0	2	2	2	4	4	6	6	6	0	18	4	12	20	2	20	0	8	16	D	D	U	U	D	D	U	U	D	D
B	1	1	3	3	3	5	5	7	7	7	2	20	0	8	16	0	18	4	12	20	U	U	D	D	U	U	D	D	U	U
C	0	0	2	2	4	4	4	6	6	6	5	15	4	16	0	15	20	2	10	18	U	U	D	D	U	U	D	D	U	U
D	1	1	3	3	5	5	5	7	7	7	4	16	5	15	2	10	18	0	15	20	D	D	U	U	D	D	U	U	D	D
E	0	0	0	2	2	2	4	4	6	6	0	8	16	4	12	20	2	20	0	18	D	D	U	U	D	D	U	U	D	D
F	1	1	1	3	3	3	5	5	7	7	4	12	20	0	8	16	0	18	2	20	U	U	D	D	U	U	D	D	U	U
G	0	0	2	2	2	4	4	4	6	6	4	16	2	20	2	10	18	0	15	20	U	U	D	D	U	U	D	D	U	U
H	1	1	3	3	3	5	5	5	7	7	2	20	4	16	0	15	20	2	10	18	D	D	U	U	D	D	U	U	D	D

FIG. 23A

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Vehicle Configuration Series

Config	Visor										Convertible Top									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
A	U	D	U	D	S	U	D	U	D	S	U	U	U	U	U	D	D	D	D	D
B	D	U	D	U	S	D	U	D	U	S	D	D	D	D	D	U	U	U	U	U
C	U	D	S	U	D	U	D	S	U	D	D	D	D	D	D	U	U	U	U	U
D	D	U	S	D	U	D	U	S	D	U	U	U	U	U	U	D	D	D	D	D
E	D	U	D	S	D	U	D	S	U	D	U	U	U	U	U	D	D	D	D	D
F	U	D	U	S	D	U	D	S	U	D	D	D	D	D	D	U	U	U	U	U
G	U	S	D	U	D	U	D	U	S	D	D	D	D	D	D	U	U	U	U	U
H	D	S	U	D	U	D	U	D	S	U	U	U	U	U	U	D	D	D	D	D

FIG. 23B

Sequence for Child Seat Training Data Collection:

Start object in center of the seat. Trainer has both hands on the steering wheel;

With a smooth motion, push the object fully outboard, then pull it fully inboard, then push it to center position, then put hands back on the steering wheel;

With a smooth motion, rotate the object 45 degrees outboard, the rotate 45 degrees inboard, then rotate back to center, then put hands back on the steering wheel;

Sequence for Out-of-Position Forward Facing Child Seat Training Data Collection

Start with object in the center line, leaning onto the Instrument Panel;

With a smooth motion, push the object fully outboard, then pull it fully inboard, then push it to the center;

Repeat this sequence with a 1 50 mm (6”) gap between the object and the Instrument Panel; Apply small (+/- 10°) rotations.

Repeat this sequence with a 300 mm (12”) gap between the object and the Instrument Panel; Apply small (+/- 10°) rotations.

FIG. 23C

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Sequence for Human Subject Training Data Collection:

Lean forward and outboard such that head and/or shoulders touch the Fire line;

Gently traverse inboard while carefully following the Fire line until the center of the vehicle is reached;

Lean halfway back towards the seatback and traverse outboard up against the side window. Rotate torso while doing so;

Lean back into the seat and traverse inboard towards the center. Rotate torso while doing so;

Sit back in the seat; "operate" radio controls, glove box, window, or seat controls; assume a brace posture;

Do *not* cross the Fire line with head and/or shoulders at any time.

Sequence for Out-of-Position Human Subject Training Data Collection:

Lean forward and outboard such that head and/or shoulders touch the Instrument Panel;

Gently traverse inboard towards the center console;

Move back 150 mm (6") and gently traverse back to the most outboard position;

Move back 300 mm (12") and gently traverse back to the center console;

"Operate" radio controls and glovebox while head and/or shoulders remain in front of the Fire line.

FIG. 23D

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Network Training Set Collection Matrix (Vehicle E)
Rev 1.1

#	Class	Subject/Object	Attributes	Actions	Config	Belt	Conditions
1	ES	None	None	Motions of track and recline	(A)	N.A.	Ambient
2	FFA	A22	Medium Clothes, Magazine	Motions in safe seating area	B	Yes	Ambient
3	OOP	A22	Medium Clothes	Motions in NFZ	C	No	Ambient
4	FFC	Century 1000	Infant Doll	Motions in safe seating area	D	No	Ambient
5	RFS	Century 1000	Baby Doll	Motions in entire seating area	E	No	Ambient
6	ES	None	Beaded Cover	Motions of track and recline	(F)	N.A.	Ambient
7	FFA	A11	Medium Clothes	Motions in safe seating area	G	Yes	Ambient
8	OOP	Touriva	Infant Doll, Blanket	Motions in NFZ	H	No	Ambient
9	FFC	Touriva	Infant Doll, Blanket	Motions in safe seating area	A	No	Ambient
10	RFS	Century 590	Baby Doll, Hood	Motions in entire seating area	B	No	Ambient
11	ES	None	Fabric Cover	Motions of track and recline	(C)	N.A.	Ambient
12	FFA	A33	Medium Clothes, Newspaper	Motions in safe seating area	D	No	Ambient
13	OOP	A33	Medium Clothes	Motions in NFZ	E	Yes	Ambient
14	FFC	C22	Medium Clothes	Motions in safe seating area	F	No	Ambient
15	RFS	Touriva	Baby Doll, Blanket	Motions in entire seating area	G	No	Ambient
16	ES	None	Blanket	Motions of track and recline	(H)	N.A.	Ambient
17	FFA	A21	Heavy Clothes	Motions in safe seating area	A	No	Ambient
18	OOP	C11	Heavy Clothes	Motions in NFZ (standing)	B	No	Ambient
19	FFC	C11	Heavy Clothes	Motions in safe seating area	C	No	Ambient

FIG. 24A

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20	RFS	TLC	Baby Doll	Motions in entire seating area	D	No	Ambient
21	ES	None	None	Motions of track and recline	(E)	N.A.	Solar Heat
22	FFA	A12	Light Clothes, Magazine	Motions in safe seating area	F	Yes	Solar Heat
23	OOP	A12	Light Clothes	Motions in NFZ	G	No	Solar Heat
24	FFC	Champion	Infant Doll	Motions in safe seating area	H	No	Solar Heat
25	RFS	Champion	Baby Doll	Motions in entire seating area	A	No	Solar Heat
26	ES	None	Beaded Cover	Motions of track and recline	(B)	N.A.	Solar Heat
27	FFA	A23	Light Clothes	Motions in safe seating area	C	Yes	Solar Heat
28	OOP	Vario Exclusive	Child Doll	Motions in NFZ	D	No	Solar Heat
29	FFC	Vario Exclusive	Child Doll, Blanket	Motions in safe seating area	E	No	Solar Heat
30	RFS	Joyride (new)	Baby Doll	Motions in entire seating area	F	No	Solar Heat
31	ES	None	Fabric Cover	Motions of track and recline	(G)	N.A.	Solar Heat
32	FFA	A32	Light Clothes, Newspaper	Motions in safe seating area	H	No	Solar Heat
33	OOP	A32	Light Clothes	Motions in NFZ	A	Yes	Solar Heat
34	FFC	C33	Light Clothes	Motions in safe seating area	B	No	Solar Heat
35	RFS	Ultara	Baby Doll, Blanket	Motions in entire seating area	C	No	Solar Heat
36	ES	None	Blanket	Motions of track and recline	(D)	N.A.	Solar Heat
37	FFA	A22	Medium Clothes	Motions in safe seating area	E	No	Solar Heat
38	OOP	C21	Medium Clothes	Motions in NFZ	F	No	Solar Heat
39	FFC	C21	Medium Clothes	Motions in safe seating area	G	No	Solar Heat
40	RFS	Arriva	Baby Doll, Hood	Motions in entire seating area	H	No	Solar Heat
41	ES	None	Handbag	Motions of track and recline	(H)	N.A.	Ambient
42	FFA	A11	Heavy Clothes, Magazine	Motions in safe seating area	G	Yes	Ambient

FIG. 24B

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43	OOP	A11	Heavy Clothes	Motions in NFZ	F	No	Ambient
44	FFC	Gerry Booster	Infant Doll	Motions in safe seating area	E	No	Ambient
45	RFS	Fisher Price CS	Baby Doll	Motions in entire seating area	D	No	Ambient
46	ES	None	Beaded Cover, Handbag	Motions of track and recline	(C)	N.A.	Ambient
47	FFA	A33	Heavy Clothes	Motions in safe seating area	B	Yes	Ambient
48	OOP	Ultara	Inflant Doll, Blanket	Motions in NFZ	A	No	Ambient
49	FFC	Ultara	Inflant Doll, Blanket	Motions in safe seating area	H	No	Ambient
50	RFS	Baby Safe	Baby Doll, Handle up	Motions in entire seating area	G	No	Ambient
51	ES	None	Fabric Cover, Handbag	Motions of track and recline	(F)	N.A.	Ambient
52	FFA	A21	Heavy Clothes, Newspaper	Motions in safe seating area	E	No	Ambient
53	OOP	A21	Heavy Clothes	Motions in NFZ	D	Yes	Ambient
54	FFC	C12	Heavy Clothes	Motions in safe seating area	C	No	Ambient
55	RFS	Vario Exclusive	Baby Doll, Blanket	Motions in entire seating area	B	No	Ambient
56	ES	None	Blanket, Handbag	Motions of track and recline	(A)	N.A.	Ambient
57	FFA	A12	Rain Clothes	Motions in safe seating area	H	No	Ambient
58	OOP	C23	Rain Clothes	Motions in NFZ	G	No	Ambient
59	FFC	C23	Rain Clothes	Motions in safe seating area	F	No	Ambient
60	RFS	Rock'n'Ride	Baby Doll	Motions in entire seating area	E	No	Ambient
61	ES	None	None	Motions of track and recline	(D)	N.A.	Air Conditioner
62	FFA	A23	Light Clothes, Magazine	Motions in safe seating area	C	Yes	Air Conditioner

FIG. 24C

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63	OOP	A23	Light Clothes	Motions in NFZ	B	No	Air Conditioner
64	FFC	Century Ovation	Inflant Doll	Motions in safe seating area	A	No	Air Conditioner
65	RFS	Century Ovation	Baby Doll	Motions in entire seating area	H	No	Air Conditioner
66	ES	None	Beaded Cover	Motions of track and recline	(G)	N.A.	Air Conditioner
67	FFA	A32	Light Clothes	Motions in safe seating area	F	Yes	Air Conditioner
68	OOP	Fisher Price CS	Child Doll	Motions in NFZ	E	No	Air Conditioner
69	FFC	Fisher Price CS	Child Doll, Blanket	Motions in safe seating area	D	No	Air Conditioner
70	RFS	Gerry Guard	Baby Doll	Motions in entire seating area	C	No	Air Conditioner
71	ES	None	Fabric Cover	Motions of track and recline	(B)	N.A.	Air Conditioner
72	FFA	A22	Light Clothes, Newspaper	Motions in safe seating area	A	No	Air Conditioner
73	OOP	A22	Light Clothes	Motions in NFZ	H	Yes	Air Conditioner
74	FFC	C32	Light Clothes	Motions in safe seating area	G	No	Air Conditioner
75	RFS	Smartmove 5T	Baby Doll, Blanket	Motions in entire seating area	F	No	Air Conditioner
76	ES	None	Blanket	Motions of track and recline	(E)	N.A.	Air Conditioner
77	FFA	A11	Medium Clothes	Motions in safe seating area	D	No	Air Conditioner
78	OOP	C22	Medium Clothes	Motions in NFZ	C	No	Air Conditioner
79	FFC	C22	Medium Clothes	Motions in safe seating area	B	No	Air Conditioner
80	RFS	Discovery	Baby Doll, Handle up	Motions in entire seating area	A	No	Air Conditioner
81	ES	None	Pizza Box	Motions of track and recline	(B)	N.A.	Ambient
82	FFA	A33	Rain Clothes, Magazine	Motions in safe seating area	A	Yes	Ambient
83	OOP	A33	Rain Clothes	Motions in NFZ	D	Yes	Ambient
84	FFC	Champion	Infant Doll	Motions in safe seating area	C	No	Ambient

FIG. 24D

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85	RFS	Champion	Baby Doll	Motions in entire seating area	F	No	Ambient
86	ES	None	Beaded Cover, Pizza Box	Motions of track and recline	(E)	N.A.	Ambient
87	FFA	A21	Rain Clothes	Motions in safe seating area	H	Yes	Ambient
88	OOP	Vario Exclusive	Child Doll, Blanket	Motions in NFZ	G	No	Ambient
89	FFC	Vario Exclusive	Child Doll, Blanket	Motions in safe seating area	B	No	Ambient
90	RFS	Joyride (new)	Baby Doll, Hood	Motions in entire seating area	A	No	Ambient
91	ES	None	Fabric Cover, Pizza Box	Motions of track and recline	(D)	N.A.	Ambient
92	FFA	A12	Rain Clothes, Newspaper	Motions in safe seating area	C	No	Ambient
93	OOP	A12	Rain Clothes	Motions in NFZ	F	No	Ambient
94	FFC	C23	Rain Clothes	Motions in safe seating area	E	No	Ambient
95	RFS	Ultara	Baby Doll, Blanket	Motions in entire seating area	H	No	Ambient
96	ES	None	Blanket, Pizza Box	Motions of track and recline	(G)	N.A.	Ambient
97	FFA	A23	Light Clothes	Motions in safe seating area	B	No	Ambient
98	OOP	C32	Light Clothes	Motions in NFZ	A	No	Ambient
99	FFC	C32	Light Clothes	Motions in safe seating area	D	No	Ambient
100	RFS	Arriva	Baby Doll, Hood	Motions in entire seating area	C	No	Ambient
101	ES	None	None	Motions of track and recline	(F)	N.A.	Car Heat
102	FFA	A32	Light Clothes, Magazine	Motions in safe seating area	E	Yes	Car Heat
103	OOP	A32	Light Clothes	Motions in NFZ	H	Yes	Car Heat
104	FFC	Century 1000	Infant Doll	Motions in safe seating area	G	No	Car Heat
105	RFS	Century 1000	Baby Doll	Motions in entire seating area	B	No	Car Heat
106	ES	None	Beaded Cover	Motions of track and recline	(A)	N.A.	Car Heat

FIG. 24E

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107	FFA	A22	Rain Clothes	Motions in safe seating area	D	Yes	Car Heat
108	OOP	Vario Exclusive	Inflant Doll	Motions in NFZ	C	No	Car Heat
109	FFC	Touriva	Inflant Doll, Blanket	Motions in safe seating area	F	No	Car Heat
110	RFS	Century 590	Baby Doll	Motions in entire seating area	E	No	Car Heat
111	ES	None	Fabric Cover	Motions of track and recline	(H)	N.A.	Car Heat
112	FFA	A11	Light Clothes, Newspaper	Motions in safe seating area	G	No	Car Heat
113	OOP	A11	Light Clothes	Motions in NFZ	B	No	Car Heat
114	FFC	C32	Light Clothes	Motions in safe seating area	A	No	Car Heat
115	RFS	Touriva	Baby Doll, Blanket	Motions in entire seating area	D	No	Car Heat
116	ES	None	Blanket	Motions of track and recline	(C)	N.A.	Car Heat
117	FFA	A33	Heavy Clothes	Motions in safe seating area	F	No	Car Heat
118	OOP	C22	Heaby Clothes	Motions in NFZ	E	No	Car Heat
119	FFC	C22	Heavy Clothes	Motions in safe seating area	H	No	Car Heat
120	RFS	TLC	Baby Doll	Motions in entire seating area	G	No	Car Heat
121	ES	None	Attaché Case (flat)	Motions of track and recline	(G)	N.A.	Ambient
122	FFA	A21	Heavy Clothes, Magazine	Motions in safe seating area	H	Yes	Ambient
123	OOP	A21	Heavy Clothes	Motions in NFZ	E	Yes	Ambient
124	FFC	Century Ovation	Infant Doll	Motions in safe seating area	F	No	Ambient
125	RFS	Century Ovation	Baby Doll	Motions in entire seating area	C	No	Ambient
126	ES	None	Beaded Cover, Attaché Case	Motions of track and recline	(D)	N.A.	Ambient
127	FFA	A12	Rain Clothes	Motions in safe seating area	A	Yes	Ambient
128	OOP	Fisher Price CS	Inflant Doll, Blanket	Motions in NFZ	B	No	Ambient

FIG. 24F

129	FFC	Fisher Price CS	Inflant Doll	Motions in safe seating area	G	No	Ambient
130	RFS	Gerry Guard	Baby Doll, Handle up	Motions in entire seating area	H	No	Ambient
131	ES	None	Fabric Cover, Attaché Case	Motions of track and recline	(E)	N.A.	Ambient
132	FFA	A23	Heavy Clothes, Newspaper	Motions in safe seating area	F	No	Ambient
133	OOP	A23	Heavy Clothes	Motions in NFZ	C	No	Ambient
134	FFC	C11	Heavy Clothes	Motions in safe seating area	D	No	Ambient
135	RFS	Smartmove 5T	Baby Doll, Blanket	Motions in entire seating area	A	No	Ambient
136	ES	None	Blanket, Attaché Case	Motions of track and recline	(B)	N.A.	Ambient
137	FFA	A32	Rain Clothes	Motions in safe seating area	G	No	Ambient
138	OOP	C33	Rain Clothes	Motions in NFZ	H	No	Ambient
139	FFC	C33	Rain Clothes	Motions in safe seating area	E	No	Ambient
140	RFS	Discovery	Baby Doll, Handle up	Motions in entire seating area	F	No	Ambient
141	ES	None	Hand Bag	Motions of track and recline	(C)	N.A.	Solar Heat
142	FFA	A22	Medium Clothes, Magazine	Motions in safe seating area	D	Yes	Solar Heat
143	OOP	A22	Heavy Clothes	Motions in NFZ	A	Yes	Solar Heat
144	FFC	Gerry Booster	Child Doll	Motions in safe seating area	B	No	Solar Heat
145	RFS	Fisher Price CS	Baby Doll	Motions in entire seating area	G	No	Solar Heat
146	ES	None	Beaded Cover, Hand Bag	Motions of track and recline	(H)	N.A.	Solar Heat

FIG. 24G

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147	FFA	A11	Medium Clothes	Motions in safe seating area	E	Yes	Solar Heat
148	OOP	Vario Exclusive	Inflant Doll	Motions in NFZ	F	No	Solar Heat
149	FFC	Ultara	Inflant Doll, Blanket	Motions in safe seating area	C	No	Solar Heat
150	RFS	Baby Safe	Baby Doll	Motions in entire seating area	D	No	Solar Heat
151	ES	None	Fabric Cover, Hand Bag	Motions of track and recline	(A)	N.A.	Solar Heat
152	FFA	A33	Medium Clothes, Newspaper	Motions in safe seating area	B	No	Solar Heat
153	OOP	A33	Medium Clothes	Motions in NFZ	G	No	Solar Heat
154	FFC	C33	Medium Clothes	Motions in safe seating area	H	No	Solar Heat
155	RFS	Vario Exclusive	Baby Doll, Blanket	Motions in entire seating area	E	No	Solar Heat
156	ES	None	Blanket, Hand Bag	Motions of track and recline	(F)	N.A.	Solar Heat
157	FFA	A21	Light Clothes	Motions in safe seating area	C	No	Solar Heat
158	OOP	C21	Light Clothes	Motions in NFZ	D	No	Solar Heat
159	FFC	C21	Light Clothes	Motions in safe seating area	A	No	Solar Heat
160	RFS	Rock'n'Ride	Baby Doll	Motions in entire seating area	B	No	Solar Heat

FIG. 24H

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Network Independent Test Set Collection Matrix (Vehicle E)
Rev 1.1 (Under Construction)

#	Class	Subject/ Object	Attributes	Actions	Config.	Belt	Conditions
1	ES			Motions of track and recline	(A)	N.A.	Ambient
2	FFA			Motions in safe seating area	B	Yes	Ambient
3	OOP			Motions in NFZ	C	No	Ambient
4	FFC			Motions in safe seating area	D	No	Ambient
5	RFS			Motions in entire seating area	E	No	Ambient
6	ES			Motions of track and recline	(F)	N.A.	Ambient
7	FFA			Motions in safe seating area	G	Yes	Ambient
8	OOP			Motions in NFZ	H	No	Ambient
9	FFC			Motions in safe seating area	A	No	Ambient
10	RFS			Motions in entire seating area	B	No	Ambient
11	ES			Motions of track and recline	(C)	N.A.	Ambient
12	FFA			Motions in safe seating area	D	No	Ambient
13	OOP			Motions in NFZ	E	Yes	Ambient
14	FFC			Motions in safe seating area	F	No	Ambient
15	RFS			Motions in entire seating area	G	No	Ambient
16	ES			Motions of track and recline	(H)	N.A.	Ambient
17	FFA			Motions in safe seating area	A	No	Ambient
18	OOP			Motions in NFZ (standing)	B	No	Ambient
19	FFC			Motions in safe seating area	C	No	Ambient
20	RFS			Motions in entire seating area	D	No	Ambient

FIG. 25

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CHARACTERISTICS OF THE DATA SETS

DATA SET	CONFIGURATIONS	SETUPS	VECTORS
TRAINING	130	1300	650,000
INDEPENDENT TEST	130	1300	195,000
VALIDATION	100	100	15,000

FIG. 26

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DISTRIBUTION OF MAIN TRAINING SUBJECTS

OCCUPANCY	REPRESENTATION
EMPTY SEAT	10 %
HUMAN OCCUPANT	32 %
CHILD SEAT	58 %

FIG. 27

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CHILD SEAT DISTRIBUTION

CHILD SEAT CONFIGURATION	REPRESENTATION
FORWARD FACING CHILD SEAT	40 %
FORWARD FACING CHILD SEAT OUT - OF-POSITION	4 %
REARWARD FACING CHILD SEAT	27 %
REARWARD FACING INFANT SEAT	29 %

FIG. 28

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DISTRIBUTION OF ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITION	REPRESENTATION
AMBIENT	56 %
STATIC HEAT (SOLAR LAMP)	25 %
DYNAMIC HEAT (CAR HEAT)	13 %
DYNAMIC COOLING (CAR A C)	6 %

FIG. 29

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VALIDATION DATA DISTRIBUTION

OCCUPANCY	REPRESENTATION
EMPTY SEAT	8 %
HUMAN OCCUPANT	39 %
CHILD SEAT	53 %

FIG. 30

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HUMAN SUBJECT DISTRIBUTION

HUMAN OCCUPANT	REPRESENTATION	NORMALLY SEATED	OUT-OF-POSITION
CHILD AGE 3	15 %	50 %	50 %
CHILD AGE 6	15 %	50 %	50 %
ADULT 5TH PERCENTILE FEMALE	23 %	67 %	33 %
ADULT 50TH PERCENTILE MALE	23 %	67 %	33 %
ADULT 95TH PERCENTILE MALE	23 %	67 %	33 %

FIG. 31

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CHILD SEAT DISTRIBUTION

CHILD SEAT CONFIGURATION	REPRESENTATION
FORWARD FACING CHILD SEAT	11 %
FORWARD FACING BOOSTER SEAT	11 %
REARWARD FACING CHILD SEAT	38 %
REARWARD FACING INFANT SEAT	40 %

FIG. 32

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DISTRIBUTION OF ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITION	REPRESENTATION
AMBIENT	63 %
STATIC HEAT (SOLAR LAMP)	13 %
DYNAMIC HEAT (CAR HEAT)	12 %
DYNAMIC COOLING (CAR AIR CONDITIONER)	12 %

FIG. 33

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TRANSDUCER VOLUME

TRANS-DUCER	STARTING POINT			END POINT		
	SAMPLE	TIME (MS)	DISTANCE (MM)	SAMPLE	TIME (MS)	DISTANCE (MM)
A	5	0.83	142	29	4.84	822
B	3	0.50	85	35	5.84	992
C	7	1.17	198	34	5.67	964
H	2	0.33	57	32	5.34	907

FIG. 34

BASELINE NETWORK PERFORMANCE

SELF TEST SUCCESS RATE	95.3 %
INDEPENDENT TEST SUCCESS RATE	94.5 %
VALIDATION TEST SUCCESS RATE	92.7 %

FIG. 35

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PERFORMANCE PER OCCUPANCY SUBSET

OCCUPANCY	INDEPENDENT TEST
EMPTY SEAT	96.1 %
NORMALLY SEATED ADULT	92.1 %
REARWARD FACING CHILD/INFANT SEAT	94.1 %
FORWARD FACING CHILD SEAT	96.9 %
OUT-OF-POSITION HUMAN/FFCS	93.0 %

FIG. 36

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PERFORMANCE PER ENVIRONMENTAL CONDITIONS SUBSET

ENVIRONMENTAL CONDITION	INDEPENDENT TEST
AMBIENT	95.4 %
LONG TERM HEAT (LAMP HEAT)	95.2 %
SORT TERM HEATING/COOLING (HVAC)	93.5 %

FIG. 37

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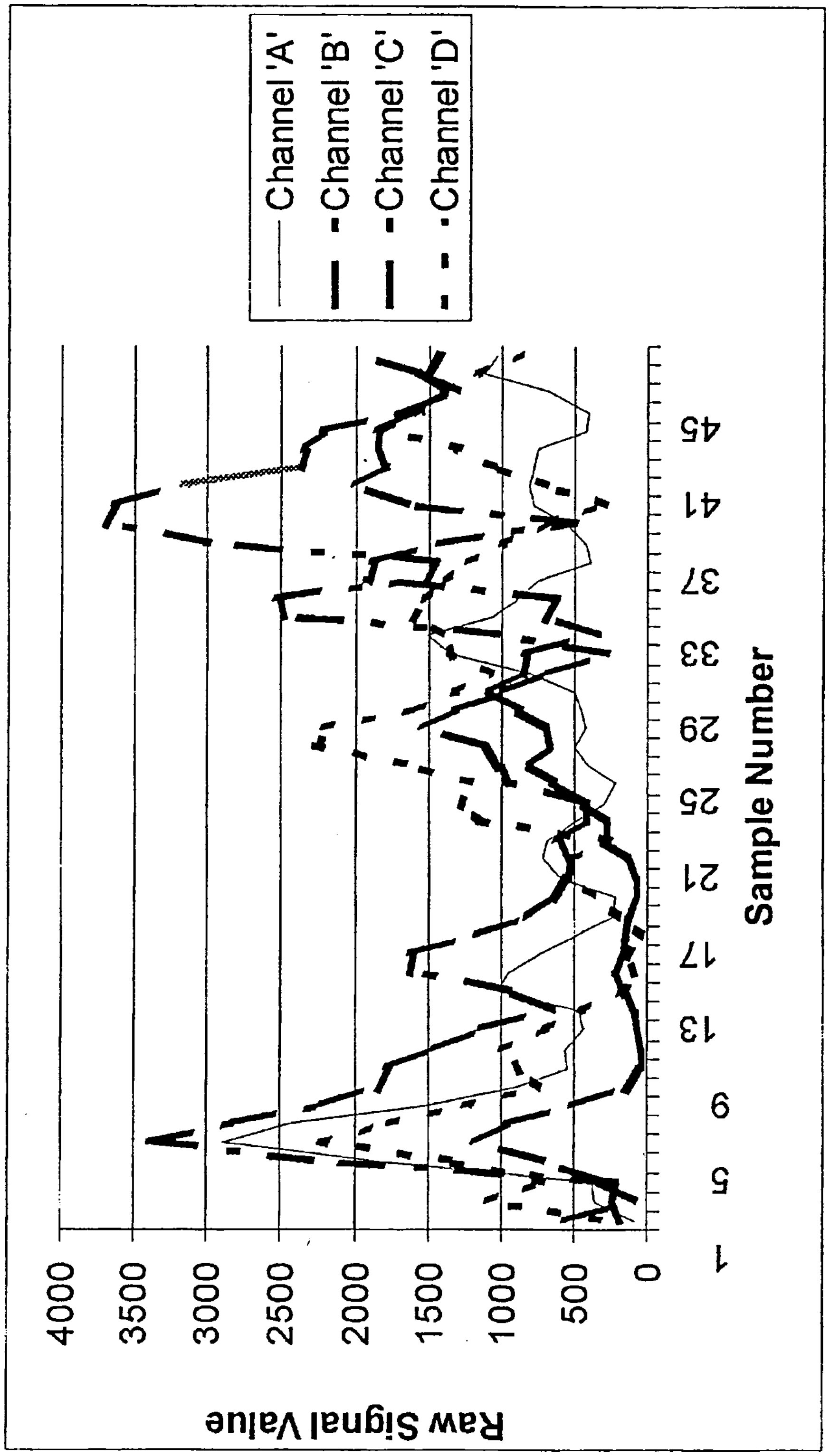

FIG. 38

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NORMALIZATION STUDY RESULTS

NORMALIZATION METHOD	SELF TEST	INDEPENDENT TEST	VALIDATION TEST
A. WHOLE VECTOR (BASE)	95.3 %	94.5 %	92.7 %
B. PER CHANNEL	94.9 %	93.8 %	90.3 %
C. FIXED RANGE [0,4095]	95.6 %	90.3 %	88.3 %

FIG. 39

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LOW THRESHOLD FILTER STUDY RESULTS

THRESHOLD LEVEL	SELF TEST	INDEPENDENT TEST	VALIDATION TEST
NONE (BASE)	95.3 %	94.5 %	92.7 %
5% OF 4095	95.3 %	94.4 %	91.9 %
10% OF 4095	95.3 %	94.3 %	92.5 %
20% OF 4095	95.1 %	94.2 %	86.4 %

FIG. 40

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SYSTEM FOR DETERMINING THE OCCUPANCY STATE OF A SEAT IN A VEHICLE AND CONTROLLING A COMPONENT BASED THEREON

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 09/853,118 filed May 10, 2001, now U.S. Pat. No. 6,445,988, which in turn is a continuation-in-part of U.S. patent application Ser. No. 09/474,147 filed Dec. 29, 1999, now U.S. Pat. No. 6,397,136, which claims the benefit of U.S. provisional patent application Ser. No. 60/136,163 filed May 27, 1999 and which turn is a continuation-in-part of U.S. patent application Ser. No. 09/382,406 filed Aug. 24, 1999, now U.S. Pat. No. 6,529, 809, which in turn is a continuation-in-part of U.S. patent application Ser. No. 08/919,823 Filed Aug. 28, 1997, now U.S. Pat. No. 5,943,295, which in turn is a continuation-in-part of U.S. patent application Ser. No. 08/798,029 filed Feb. 6, 1997, now abandoned.

This application is related to: (i) U.S. Pat. No. 5,653,462 entitled "Vehicle Occupant Position and Velocity Sensor" filed Jul. 21, 1995, which is a continuation of U.S. patent application Ser. No. 08/040,978 filed Mar. 31, 1993, now abandoned, which in turn is a continuation of U.S. patent application Ser. No. 07/878,571 filed May 5, 1992, now abandoned; (ii) U.S. Pat. No. 5,829,782 entitled "Vehicle Interior Identification and Monitoring System" filed May 9, 1994; (iii) U.S. Pat. No. 5,845,000 entitled "Optical Identification and Monitoring System Using Pattern Recognition for Use with Vehicles" filed Jun. 7, 1995; (iv) U.S. Pat. No. 5,822,707 entitled "Automatic Vehicle Seat Adjuster" filed Jun. 7, 1995; (v) U.S. Pat. No. 5,748,473 entitled "Automatic Vehicle Seat Adjuster" filed Jun. 7, 1995; and (vi) U.S. Pat. No. 5,835,613 entitled "Optical Identification and Monitoring System Using Pattern Recognition for use with Vehicles" filed Jun. 7, 1995, which are all incorporated by reference herein.

FIELD OF THE INVENTION

The present invention relates generally to the field of determining the occupancy state of the vehicle which entails sensing, detecting, monitoring and/or identifying various objects, and parts thereof, which are located within the passenger compartment of the vehicle. The occupancy state is a broad or narrow description of the state or condition of one or more occupying items in the vehicle. Thus, a determination of the occupancy state may include a determination of the type or class of any occupying items, the size of any occupying items, the position of any occupying item including the orientation of occupying items, the identification of any occupying items and/or the status of any occupying items (whether the occupying items are conscious or unconscious). The determination of the occupancy state is used to control a vehicular component.

In particular, the present invention relates to an efficient and highly reliable system for evaluating the occupancy of a vehicle by detecting the presence and optionally orientation of objects in the seats of the passenger compartment, e.g., a rear facing child seat (RFCS) situated in the passenger compartment in a location where it may interact with a deploying occupant protection apparatus, such as an airbag, and/or for detecting an out-of-position occupant. The system permits the control and selective suppression of deployment of the occupant protection apparatus when the deployment may result in greater injury to the occupant than the crash forces themselves. This is accomplished in part through a specific placement of transducers of the system, the use of a pattern recognition system, possibly a trained neural network and combinations of neural networks called modular neural, voting or ensemble neural networks, support vector machines, cellular neural networks and/or a novel analysis of the signals from the transducers.

BACKGROUND OF THE INVENTION

1. Prior Art on Sensing of Out-of-Position Occupants and Rear Facing Child Seats

Whereas thousands of lives have been saved by airbags, a large number of people have also been injured, some seriously, by the deploying airbag, and thus significant improvements to the airbag system are necessary. As discussed in detail in one or more of the patents and patent applications cross-referenced above, for a variety of reasons, vehicle occupants may be too close to the airbag before it deploys and can be seriously injured or killed as a result of any deployment thereof. Also, a child in a rear facing child seat which is placed on the right front passenger seat is in danger of being seriously injured if the passenger airbag deploys. For these reasons and, as first publicly disclosed in Breed, D. S. "How Airbags Work" presented at the International Conference on Seatbelts and Airbags in 1993, in Canada, occupant position sensing and rear facing child seat detection is required in order to minimize the damages caused by deploying airbags. It also may be required in order to minimize the damage caused by the deployment of other types of occupant protection and/or restraint devices which might be installed in the vehicle

Initially, these systems will solve the out-of-position occupant and the rear facing child seat problems related to current airbag systems and prevent unneeded and unwanted airbag deployments when a front seat is unoccupied. However, airbags are now under development to protect rear seat occupants in vehicle crashes and all occupants in side impacts. A system is therefore needed to detect the presence of occupants, determine if they are out-of-position, defined below, and to identify the presence of a rear facing child seat in the rear seat. Future automobiles are expected to have eight or more airbags as protection is sought for rear seat occupants and from side impacts. In addition to eliminating the disturbance and possible harm of unnecessary airbag deployments, the cost of replacing these airbags will be excessive if they all deploy in an accident needlessly.

Inflators now exist which will adjust the amount of gas flowing to or from the airbag to account for the size and position of the occupant and for the severity of the accident. The vehicle identification and monitoring system (VIMS) discussed in U.S. Pat. Nos. 5,829,782, and 5,943,295 among others, will control such inflators based on the presence and position of vehicle occupants or of a rear facing child seat. The instant invention is concerned with the process of adapting the vehicle interior monitoring systems to a particular vehicle model and achieving a high system accuracy and reliability as discussed in greater detail below as well as the resulting pattern recognition system architecture.

The automatic adjustment of the deployment rate of the airbag based on occupant identification and position and on crash severity has been termed "smart airbags". Central to the development of smart airbags is the occupant identification and position determination systems described in the above-referenced patents and patent applications and to the methods described herein for adapting those systems to a particular vehicle model. To complete the development of smart airbags, an anticipatory crash detecting system such as

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disclosed in U.S. Pat. No. 6,343,810 is also desirable. Prior to the implementation of anticipatory crash sensing, the use of a neural network smart crash sensor which identifies the type of crash and thus its severity based on the early part of the crash acceleration signature should be developed and thereafter implemented. U.S. Pat. No. 5,684,701 (Breed) describes a crash sensor based on neural networks. This crash sensor, as with all other crash sensors, determines whether or not the crash is of sufficient severity to require deployment of the airbag and, if so, initiates the deployment A neural network based on a smart airbag crash sensor could also be designed to identify the crash and categorize it with regard to severity thus permitting the airbag deployment to be matched not only to the characteristics and position of the occupant but also the severity and timing of the crash itself as described in more detail in U.S. Pat. No. 5,943,295 referenced above.

The need for an occupant out-of-position sensor has also been observed by others and several methods have been described in certain U.S. patents for determining the position of an occupant of a motor vehicle. However, no patents have been found that describe the methods of adapting such sensors to a particular vehicle model to obtain high system accuracy or to a resulting architecture combination of pattern recognition algorithms. Each of these systems will be discussed below and have significant limitations.

In White et al. (U.S. Pat. No. 5,071,160), for example, a single acoustic sensor and detector is described and, as illustrated, is disadvantageously mounted lower than the steering wheel. White et al. correctly perceive that such a sensor could be defeated, and the airbag falsely deployed, by an occupant adjusting the control knobs on the radio and thus they suggest the use of a plurality of such sensors. White et al. does not disclose where the such sensors would be mounted, other than on the instrument panel below the steering wheel, or how they would be combined to uniquely monitor particular locations in the passenger compartment and to identify the object(s) occupying those locations The adaptation process to vehicles is not described nor is a combination of pattern recognition algorithms.

Mattes et al. (U.S. Pat. No. 5,118,134) describe a variety of methods for measuring the change in position of an occupant including ultrasonic, active or passive infrared radiation, microwave radar sensors, and an electric eye. The use of these sensors is to measure the change in position of an occupant during a crash and they use that information to assess the severity of the crash and thereby decide whether or not to deploy the airbag. They are thus using the occupant motion as a crash sensor. No mention is made of determining the out-of-position status of the occupant or of any of the other features of occupant monitoring as disclosed in the above-referenced patents and/or patent applications. It is interesting to note that nowhere does Mattes et al. discuss how to use a combination of ultrasonic sensors/transmitters to identify the presence of a human occupant and then to find his/her location in the passenger compartment or any pattern recognition algorithm let alone a combination of such algorithms.

The object of an occupant out-of-position sensor is to determine the location of the head and/or chest of the vehicle occupant in the passenger compartment relative to the occupant protection apparatus, such as an airbag, since it is the impact of either the head or chest with the deploying airbag which can result in serious injuries. Both White et at. and Mattes et al. disclose only lower mounting locations of their sensors which are mounted in front of the occupant such as on the dashboard or below the steering wheel. Both such mounting locations are particularly prone to detection errors due to positioning of the occupant's hands, arms and legs. This would require at least three, and preferably more, such sensors and detectors and an appropriate logic circuitry, or pattern recognition system, which ignores readings from some sensors if such readings are inconsistent with others, for the case, for example, where the driver's arms are the closest objects to two of the sensors. The determination of the proper transducer mounting locations, aiming and field angles and pattern recognition system architectures for a particular vehicle model are not disclosed in either White et at or Mattes et al. and are part of the vehicle model adaptation process described herein.

White et al. also describe the use of error correction circuitry, without defining or illustrating the circuitry, to differentiate between the velocity of one of the occupant's hands, as in the case where he/she is adjusting the knob on the radio, and the remainder of the occupant. Three ultrasonic sensors of the type disclosed by White et al. might, in some cases, accomplish this differentiation if two of them indicated that the occupant was not moving while the third was indicating that he or she was moving. Such a combination, however, would not differentiate between an occupant with both hands and arms in the path of the ultrasonic transmitter at such a location that they were blocking a substantial view of the occupant's head or chest. Since the sizes and driving positions of occupants are extremely varied, trained pattern recognition systems, such as neural networks and combinations thereof, are required when a clear view of the occupant, unimpeded by his/her extremities, cannot be guaranteed. White et al. do not suggest the use of such neural networks.

Fujita et al., in U.S. Pat. No. 5,074,583, describe another method of determining the position of the occupant but do not use this information to control and suppress deployment of an airbag if the occupant is out-of-position, or if a rear facing child seat is present. In fact, the closer that the occupant gets to the airbag, the faster the inflation rate of the airbag is according to the Fujita et al. patent, which thereby increases the possibility of injuring the occupant. Fujita et al. do not measure the occupant directly but instead determine his or her position indirectly from measurements of the seat position and the vertical size of the occupant relative to the seat. This occupant height is determined using an ultrasonic displacement sensor mounted directly above the occupant's head.

It is important to note that in all cases in the above-cited prior art, except those assigned to the current assignee of the instant invention, no mention is made of the method of determining transducer location, deriving the algorithms or other system parameters that allow the system to accurately identify and locate an object in the vehicle. In contrast, in one implementation of the instant invention, the return ultrasonic echo pattern over several milliseconds corresponding to the entire portion of the passenger compartment volume of interest is analyzed from multiple transducers and sometimes combined with the output from other transducers, providing distance information to many points on the items occupying the passenger compartment.

Many of the teachings of this invention are based on pattern recognition technologies as taught in numerous textbooks and technical papers. Central to the diagnostic teachings of this invention are the manner in which the diagnostic module determines a normal pattern from an abnormal pattern and the manner in which it decides what data to use from the vast amount of data available. This is accomplished using pattern recognition technologies, such

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as artificial neural networks, including support vector machines, cellular neural networks and training. The theory of neural networks including many examples can be found in several books on the subject including. (1) *Techniques And Application Of Neural Networks*, edited by Taylor, M. and Lisboa, P., Ellis Horwood, West Sussex, England, 1993; (2) *Naturally Intelligent Systems*, by Caudill, M. and Butler, C., MIT Press, Cambridge, Mass., 1990; (3) J. M. Zaruda, *Introduction to Artificial Neural Systems*, West publishing Co., N.Y., 1992, (4) *Digital Neural Networks*, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, N.J., 1993, Eberhart, R., Simpson, P., (5) Dobbins, R., *Computational Intelligence PC Tools*, Academic Press, Inc., 1996, Orlando, Fla., (6) Cristianini, N. and Shawe-Taylor, J. *An Introduction to Support Vector Machines and other kernel-based learning methods*, Cambridge University Press, Cambridge England, 2000; (7) *Proceedings of the* 2000 6th *IEEE International Workshop on Cellular Neural Networks and their Applications* (*CNNA* 2000), IEEE, Piscataway, N.J., and (8) Sinha, N. K. and Gupta, M. M. *Soft Computing & Intelligent Systems*, Academic Press 2000 San Diego, Calif., all of which are incorporated herein by reference. The neural network pattern recognition technology is one of the most developed of pattern recognition technologies. The invention described herein uses combinations of neural networks to improve the pattern recognition process.

Other patents describing occupant sensor systems include U.S. Pat. No. 5,482,314 (Corrado et al.) and U.S. Pat. No. 5,890,085 (Corrado et al.). These patents describe a system for sensing the presence, position and type of an occupant in a seat of a vehicle for use in enabling or disabling a related airbag activator. A preferred implementation of the system includes two or more different but collocated sensors which provide information about the occupant and this information is fused or combined in a microprocessor circuit to produce an output signal to the airbag controller. According to Corrado et al., the fusion process produces a decision as to whether to enable or disable the airbag with a higher reliability than a single phenomena sensor or non-fused multiple sensors. By fusing the information from the sensors to make a determination as to the deployment of the airbag, each sensor has only a partial effect on the ultimate deployment determination. The sensor fusion process is a crude pattern recognition process based on deriving the fusion "rules" by a trial and error process rather than by training.

The sensor fusion method of Corrado et al. requires that information from the sensors be combined prior to processing by an algorithm in the microprocessor. This combination could be found to unnecessarily complicate the processing of the data from the sensors and other data processing methods might provide better results. For example, as discussed more fully below, it has been found to be advantageous to use a more efficient pattern recognition algorithm such as a combination of neural networks or fuzzy logic algorithms which are arranged to receive a separate stream of data from each sensor, without that data being combined with data from the other sensors (as in done in Corrado et al.) prior to analysis by the pattern recognition algorithms. In this regard, it is critical to appreciate that sensor fusion is a form of pattern recognition but is not a neural network and that significant and fundamental differences exist between sensor fusion and neural networks. Thus, some embodiments of the invention described below differ from that of Corrado et al. because they include a microprocessor which is arranged to accept only a separate stream of data from each sensor such that the stream of data from the sensors are not combined with one another. Further, the microprocessor

processes each separate stream of data independent of the processing of the other streams of data (i.e., without the use of any fusion matrix as in Corrado et al).

2. Definitions

The use of pattern recognition, or more particularly how it is used, is important to the instant invention. In the above-cited prior art, except in that assigned to the current assignee of the instant invention, pattern recognition which is based on training, as exemplified through the use of neural networks, is not mentioned for use in monitoring the interior passenger compartment or exterior environments of the vehicle. Thus, the methods used to adapt such systems to a vehicle are also not mentioned.

"Pattern recognition" as used herein will generally mean any system which processes a signal that is generated by an object (e.g., representative of a pattern of returned or received impulses, waves or other physical property specific to and/or characteristic of and/or representative of that object) or is modified by interacting with an object, in order to determine to which one of a set of classes that the object belongs. Such a system might determine only that the object is or is not a member of one specified class, or it might attempt to assign the object to one of a larger set of specified classes, or find that it is not a member of any of the classes in the set. The signals processed are generally a series of electrical signals coming from transducers that are sensitive to acoustic (ultrasonic) or electromagnetic radiation (e.g., visible light, infrared radiation, capacitance or electric and/or magnetic fields), although other sources of information are frequently included. Pattern recognition systems generally involve the creation of a set of rules that permit the pattern to be recognized. These rules can be created by fuzzy logic systems, statistical correlations, or through sensor fusion methodologies as well as by trained pattern recognition systems such as neural networks, combination neural networks, cellular neural networks or support vector machines.

A trainable or a trained pattern recognition system as used herein generally means a pattern recognition system which is taught to recognize various patterns constituted within the signals by subjecting the system to a variety of examples. The most successful such system is the neural network used either singly or as a combination of neural networks. Thus, to generate the pattern recognition algorithm, test data is first obtained which constitutes a plurality of sets of returned waves, or wave patterns, from an object (or from the space in which the object will be situated in the passenger compartment, i.e., the space above the seat) and an indication of the identify of that object. A number of different objects are tested to obtain the unique wave patterns from each object. As such, the algorithm is generated, and stored in a computer processor, and which can later be applied to provide the identity of an object based on the wave pattern being received during use by a receiver connected to the processor and other information. For the purposes here, the identity of an object sometimes applies to not only the object itself but also to its location and/or orientation in the passenger compartment. For example, a rear facing child seat is a different object than a forward facing child seat and an out-of-position adult can be a different object than a normally seated adult.

To "identify" as used herein will generally mean to determine that the object belongs to a particular set or class. The class may be one containing, for example, all rear facing child seats, one containing all human occupants, or all human occupants not sitting in a rear facing child seat depending on the purpose of the system. In the case where

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a particular person is to be recognized, the set or class will contain only a single element, i.e., the person to be recognized

An "object" in a vehicle or an "occupying item" of a seat may be a living occupant such as a human or a dog, another living organism such as a plant, or an inanimate object such as a box or bag of groceries or an empty child seat.

"Out-of-position" as used for an occupant will generally mean that the occupant, either the driver or a passenger is sufficiently close to the occupant protection apparatus (airbag) prior to deployment that he or she is likely to be more seriously injured by the deployment event itself than by the accident. It may also mean that the occupant is not positioned appropriately in order to attain beneficial, restraining effects of the deployment of the airbag An occupant is too close to the airbag when the occupant's head or chest is closer than some distance, such as about 5 inches, from the deployment door of the airbag module. The actual distance value where airbag deployment should be suppressed depends on the design of the airbag module and is typically farther for the passenger airbag than for the driver airbag.

"Transducer" as used herein will generally mean the combination of a transmitter and a receiver. In come cases, the same device will serve both as the transmitter and receiver while in others two separate devices adjacent to each other will be used. In some cases, a transmitter is not used and in such cases transducer will mean only a receiver. Transducers include, for example, capacitive, inductive, ultrasonic, electromagnetic (antenna, CCD, CMOS arrays), weight measuring or sensing devices. In some cases, a transducer may comprise two parts such as the plates of a capacitor or the antennas of an electric field sensor. Sometimes, one antenna or plate will communicate with several other antennas or plates and thus for the purposes herein, a transducer will be broadly defined to refer, in most cases, to any one of the plates of a capacitor or antennas of a field sensor and in some other cases a pair of such plates or antennas will comprise a transducer as determined by the context in which the term is used.

"Adaptation" as used here will generally represent the method by which a particular occupant sensing system is designed and arranged for a particular vehicle model. It includes such things as the process by which the number, kind and location of various transducers is determined. For pattern recognition systems, it includes the process by which the pattern recognition system is designed and then taught or made to recognize the desired patterns. In this connection, it will usually include (1) the method of training when training is used, (2) the makeup of the databases used, testing and validating the particular system, or, in the ease of a neural network, the particular network architecture chosen, (3) the process by which environmental influences are incorporated into the system, and (4) any process for determining the pre-processing of the data or the post processing of the results of the pattern recognition system. The above list is illustrative and not exhaustive. Basically, adaptation includes all of the steps that are undertaken to adapt transducers and other sources of information to a particular vehicle to create the system which accurately identifies and/or determines the location of an occupant or other object in a vehicle.

A "combination neural network" as used herein will generally apply to any combination of two or more networks that am either connected together or that analyze all or a portion of the input data. A combination neural network can be used to divide tasks in solving a particular occupant

problem. For example, one neural network can be used to identify an object occupying a passenger compartment of an automobile and a second neural network can be used to determine the position of the object or its location with respect to the airbag, for example, within the passenger compartment. In another case, one neural network can be used merely to determine whether the data is similar to data upon which a main neural network has trained or whether there is something radically different about this data and therefore that the data should not be analyzed. Cellular neural networks are by nature combination neural networks as they involve at least two cellular networks. For the purposes herein, a neural network is defined to include all such learning systems including cellular neural networks, support vector machines and other kernel based learning systems and methods, cellular automata and all other pattern recognition methods and systems that learn. Combination neural networks are combinations of two or more such neural networks as most broadly defined

With respect to a comparative analysis performed by neural networks to that perform by the human mind, once the human mind has identified that the object observed is a tree, the mind does not try to determine whether it is the black bear or a grizzly. Further observation on the tree might center on whether it is a pine tree, an oak tree etc. Thus the human mind appears to operate in some manner like a hierarchy of neural networks. Similarly, neural networks for analyzing the occupancy of the vehicle can be structured such that higher order networks are used to determine, for example, whether there is an occupying item of any kind present. This could be followed by the neural network that, knowing that there is information on the item, attempts to categorize the item into child seats and human adults etc., i.e., determine the type of item Once it has decided that a child seat is present, then another neural network can be used to determine whether the child seat is rear facing or forward facing. Once the decision has been made that the child seat is facing rearward, the position of the child seat relative to the airbag, for example, can be handled by still another neural network. The overall accuracy of the system can be substantially improved by breaking the pattern recognition process down into a larger number of smaller pattern recognition problems.

In some cases, the accuracy of the pattern recognition process can be improved if the system uses data indicating its own recent decisions. Thus, for example, if the neural network system had determined that a forward facing adult was present, then that information can be used as input into another neural network, biasing any results toward the forward facing human compared to a rear facing child seat, for example. Similarly, for the case when an occupant is being tracked in his or her forward motion during a crash, for example, the location of the occupant at the previous calculation time step can be valuable information to determining the location of the occupant from the current data. There is a limited distance an occupant can move in 10 milliseconds, for example. In this latter example, feedback of the decision of the neural network tracking algorithm becomes important input into the same algorithm for the calculation of the position of the occupant at the next time step.

What has been described above is generally referred to as modular neural networks with and without feedback. Actually, the feedback does not have to be from the output to the input of the same neural network. The feedback from a downstream neural network could be input to an upstream neural network, for example.

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The neural networks can be combined in other ways, for example in a voting situation. Sometimes the data upon which the system is trained is sufficiently complex or imprecise that different views of the data will give different results. For example, a subset of transducers may be used to train one neural network and another subset to train a second neural network etc. The decision can then be based on a voting of the parallel neural networks, known as an ensemble neural networks. In the past, neural networks have usually only been used in the form of a single neural network algorithm for identifying the occupancy state of an automobile. This invention is primarily advancing the state of the art and using combination neural networks wherein two or more neural networks are combined to arrive at a decision Cellular neural networks, for example, are by nature combination neural networks.

In the description herein on anticipatory sensing, the term "approaching" when used in connection with the mention of an object or vehicle approaching another will generally mean the relative motion of the object toward the vehicle having the anticipatory sensor system. Thus, in a side impact with a tree, the tree will be considered as approaching the side of the vehicle and impacting the vehicle. In other words, the coordinate system used in general will be a coordinate system residing in the target vehicle. The "target" vehicle is the vehicle which is being impacted. This convention permits a general description to cover all of the cases such as where (i) a moving vehicle impacts into the side of a stationary vehicle, (ii) where both vehicles are moving when they impact, or (iii) where a vehicle is moving sideways into a stationary vehicle, tree or wall. Also, for the purposes herein, a "wave sensor" or "wave transducer" is generally any device, which senses either ultrasonic or electromagnetic waves. An electromagnetic wave sensor, for example, includes devices that sense any portion of the electromagnetic spectrum from ultraviolet down to a few hertz. The most commonly used kinds of electromagnetic wave sensors include CCD and CMOS arrays for sensing visible and/or infrared waves, millimeter wave and microwave radar, and capacitive or electric and/or magnetic field monitoring sensors that rely on the dielectric constant of the object occupying a space but also rely on the time variation of the field, expressed by waves as defined below, to determine a change in state. In this regard, reference is made to, for example, U.S. patents by Kithil et al. U.S. Pat. Nos. 5,366,241, 5,602,734, 5,691,693, 5,802,479 and 5,844,486 and Jinno et al. U.S. Pat. No. 5,948,031 which are incorporated herein by reference.

Electric and magnetic field sensors and wave sensors are essentially the same from the point of view of sensing the presence of an occupant in a vehicle. In both cases, a time varying electric and/or magnetic field is disturbed or modified by the presence of the occupant. At high frequencies in the visual, infrared and high frequency radio wave region, the sensor is based on the reflection of electromagnetic energy. As the frequency drops and more of the energy passes through the occupant, the absorption of the wave energy is measured and at still lower frequencies the occupant's dielectric and displacement current properties modify the standing wave in the occupied space between the plates of a capacitor. In this latter case, the sensor senses the change in charge distribution on the capacitor plates by measuring, for example, the current wave magnitude or phase in the electric circuit that drives the capacitor. In all cases, the presence of the occupant reflects, absorbs or modifies the waves or variations in the electric or magnetic field (standing waves) in the space occupied by the occupant. Thus, for the purposes of this invention, capacitance, electric field and magnetic field sensors are equivalent and will be considered as wave sensors. What follows is a discussion comparing the similarities and differences between two types of wave sensors, electromagnetic beam sensors and capacitive sensors as exemplified by Kithil in U.S. Pat. No. 5,702,634 which is incorporated herein by reference.

An electromagnetic field disturbed or emitted by a passenger in the case of an electromagnetic beam sensor, for example, and the electric field sensor of Kithil, for example, are in many ways similar and equivalent for the purposes of this invention The electromagnetic beam sensor is an actual electromagnetic wave sensor by definition, which is a coupled pair of continuously changing electric and magnetic fields. The electric field here is not a static, potential one. It is essentially a dynamic, vortex electric field coupled with a changing magnetic one, that is, an electromagnetic wave. It cannot be produced by a steady distribution of electric charges. It is initially produced by moving electric charges in a transmitter, even if this transmitter is a passenger body for the case of a passive infrared sensor.

In the Kithil sensor, a static electric field is declared as an initial material agent coupling a passenger and a sensor (see column 5, lines 5–7): "The proximity sensor **12** each function by creating an electrostatic field between oscillator input loop **54** and detector output loop **56**, which is affected by presence of a person near by, as a result of capacitive coupling, . . . "). It is a potential, non-vortex electric field. It is not necessarily coupled with any magnetic field. It is the electric field of a capacitor. It can be produced with a steady distribution of electric charges. Thus, it is not an electromagnetic wave by definition but if the sensor is driven by a varying current then in produces standing electric waves in the space between the plates of the capacitor

Kithil declares that he uses a static electric field in his capacitance sensor. Thus, from the consideration above, one can conclude that Kithil's sensor cannot be treated as a wave sensor because there are no actual electromagnetic, or electric, waves but only a static electric field of the capacitor in the sensor system. However this is not the case The Kithil system could not operate with a true static electric field because a steady system does not carry any information. Therefore, Kithil is forced to use an oscillator, causing an alternate current in the capacitor and a standing electric wave in the space between the capacitor plates, and a detector to reveal an informative change of the sensor capacitance caused by the presence of an occupant (see FIG. **7** and its description). In this case, his system becomes a wave sensor in the sense that it starts generating actual electric waves according to the definition above. That is, Kithil's sensor can be treated as a wave sensor regardless of the shape of the electric field that it creates, a beam or a spread shape.

As described in the Kithil patents, the capacitor sensor is a parametric system where the capacitance of the sensor is controlled by influence of the passenger body. This influence is transferred by means of the electromagnetic field (i.e., the wave process) coupling the capacitor electrodes and the body. It is important to note, that the same influence takes place with a static electric field also, that is in absence of any wave phenomenon. This would be a situation if there were no oscillator in Kithil's system. However, such a system is not workable and thus Kithil reverts to a dynamic system using electric waves.

Thus, although Kithil declares the coupling is due to a static electric field, such a situation is not realized in his

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system because an alternating electromagnetic field ("wave") exists in the system due to the oscillator. Thus, his sensor is actually a wave sensor, that is, it is sensitive to a change of a wave field in the vehicle compartment. This change is measured by measuring the change of its capacitance. The capacitance of the sensor system is determined by the configuration of its electrodes, one of which is a human body, that is, the passenger inside of and the part which controls the electrode configuration and hence a sensor parameter, the capacitance.

The physics definition of "wave" from Webster's Encyclopedic Unabridged Dictionary is: "11. Physics. A progressive disturbance propagated from point to point in a medium or space without progress or advance of the points themselves, . . . ". In a capacitor, the time that it takes for the disturbance (a change in voltage) to propagate through space, the dielectric and to the opposite plate is generally small and neglected but it is not zero. As the frequency driving the capacitor increases and the distance separating the plates increases and this transmission time as a percentage of the period of oscillation can become significant. Nevertheless, an observer between the plates will see the rise and fall of the electric field much like a person standing in the water of an ocean. The presence of a dielectric body between the plates causes the waves to get bigger as more electrons flow to and from the plates of the capacitor Thus, an occupant effects the magnitude of these waves which is sensed by the capacitor circuit. Thus, the electromagnetic field is a material agent that carries information about a passenger's position in both Kithil's and a beam type electromagnetic wave sensor.

The following definitions are from the Encyclopedia Britannica:

Electromagnetic Field

"A property of space caused by the motion of an electric charge. A stationary charge will produce only an electric field in the surrounding space. If the charge is moving, a magnetic field is also produced. An electric field can be produced also by a changing magnetic field. The mutual interaction of electric and magnetic fields produces an electromagnetic field, which is considered as having its own existence in space apart from the charges or currents (a stream of moving charges) with which it may be related . . . . " (Copyright 1994–1998 Encyclopedia Britannica)

Displacement Current

" . . . in electromagnetism, a phenomenon analogous to an ordinary electric current, posited to explain magnetic fields that are produced by changing electric fields. Ordinary electric currents, called conduction currents, whether steady or varying, produce an accompanying magnetic field in the vicinity of the current. [. . .]

"As electric charges do not flow through the insulation from one plate of a capacitor to the other, there is no conduction current; instead, a displacement current is said to be present to account for the continuity of the magnetic effects In fact, the calculated size of the displacement current between the plates of a capacitor being charged and discharged in an alternating-current circuit is equal to the size of the conduction current in the wires leading to and from the capacitor. Displacement currents play a central role in the propagation of electromagnetic radiation, such as light and radio waves, through empty space. A traveling, varying magnetic field is everywhere associated with a periodically changing electric field that may be conceived in terms of a displacement current. Maxwell's insight on displacement current, therefore, made it possible to understand electromagnetic waves as being propagated through space completely detached from electric currents in conductors." Copyright 1994–1998 Encyclopedia Britannica.

Electromagnetic Radiation

" . . . energy that is propagated through free space or through a material medium in the form of electromagnetic waves, such as radio waves, visible light, and gamma rays. The term also refers to the emission and transmission of such radiant energy [. . .]

"It has been established that time-varying electric fields can induce magnetic fields and that time-varying magnetic fields can in like manner induce electric fields. Because such electric and magnetic fields generate each other, they occur jointly, and together they propagate as electromagnetic waves. An electromagnetic wave is a transverse wave in that the electric field and the magnetic field at any point and time in the wave are perpendicular to each other as well as to the direction of propagation. [. . .]

"Electromagnetic radiation has properties in common with other forms of waves such as reflection, refraction, diffraction, and interference. [. . .]" Copyright 1994–1998 Encyclopedia Britannica.

The main part of the Kithil "circuit means" is an oscillator, which is as necessary in the system as the capacitor itself to make the capacitive coupling effect be detectable An oscillator by nature creates waves. The system can operate as a sensor only if an alternating current flows through the sensor capacitor, which, in fact, is a detector from which an informative signal is acquired. Then this current (or, more exactly, integral of the current over time—charge) is measured and the result is a measure of the sensor capacitance value. The latter in turn depends on the passenger presence that affects the magnitude of the waves that travel between the plates of the capacitor making the Kithil sensor a wave sensor by the definition herein.

An additional relevant definitions is:

Capacitive Coupling

The transfer of energy from one circuit to another by means of the mutual capacitance between the circuits. (188) Note 1: The coupling may be deliberate or inadvertent. Note 2: Capacitive coupling favors transfer of the higher frequency components of a signal, whereas inductive coupling favors lower frequency components, and conductive coupling favors neither higher nor lower frequency components."

Another similarity between one embodiment of the sensor of this invention and the Kithil sensor is the use of a voltage-controlled oscillator (VCO).

3. Pattern Recognition Prior Art

Japanese Patent No. 3-42337 (A) to Ueno describes a device for detecting the driving condition of a vehicle driver comprising a light emitter for irradiating the face of the driver and a means for picking up the image of the driver and storing it for later analysis. Means are provided for locating the eyes of the driver and then the irises of the eyes and then determining if the driver is looking to the side or sleeping. Ueno determines the state of the eyes of the occupant rather than determining the location of the eyes relative to the other parts of the vehicle passenger compartment Such a system can be defeated if the driver is wearing glasses, particularly sunglasses, or another optical device which obstructs a clear view of his/her eyes Neural networks are not used. The method of finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,008,946 to Ando uses a complicated set of rules to isolate the eyes and mouth of a driver and uses this information to permit the driver to control the radio, for

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example, or other systems within the vehicle by moving his eyes and/or mouth. Ando uses visible light and illuminates only the head of the driver. He also makes no use of trainable pattern recognition systems such as neural networks, nor is there any attempt to identify the contents of the vehicle nor of their location relative to the vehicle passenger compartment. Rather, Ando is limited to control of vehicle devices by responding to motion of the driver's mouth and eyes. As with Ueno, a method of finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,298,732, filed Feb. 18, 1993, to Chen also concentrates on locating the eyes of the driver so as to position a light filter between a light source such as the sun or the lights of an oncoming vehicle, and the driver's eyes. Chen does not explain in detail how the eyes are located but does supply a calibration system whereby the driver can adjust the filter so that it is at the proper position relative to his or her eyes. Chen references the use of an automatic equipment for determining the location of the eyes but does not describe how this equipment works. In any event, in Chen, there is no mention of monitoring the position of the occupant, other that the eyes, determining the position of the eyes relative to the passenger compartment, or identifying any other object in the vehicle other than the driver's eyes. Also, there is no mention of the use of a trainable pattern recognition system. A method for finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,305,012 to Faris also describes a system for reducing the glare from the headlights of an oncoming vehicle. Faris locates the eyes of the occupant by using two spaced apart infrared cameras using passive infrared radiation from the eyes of the driver. Faris is only interested in locating the driver's eyes relative to the sun or oncoming headlights and does not identify or monitor the occupant or locate the occupant, a rear facing child seat or any other object for that matter, relative to the passenger compartment or the airbag. Also, Faris does not use trainable pattern recognition techniques such as neural networks. Faris, in fact, does not even say how the eyes of the occupant are located but refers the reader to a book entitled Robot Vision (1991) by Berthold Horn, published by MIT Press, Cambridge, Mass. Also, Faris uses the passive infrared radiation rather than illuminating the occupant with ultrasonic or electromagnetic radiation as in some implementations of the instant invention. A method for finding the eyes of the occupant is described but not a method of adapting the system to a particular vehicle model.

The use of neural networks, or neural fuzzy systems, and in particular combination neural networks, as the pattern recognition technology and the methods of adapting this to a particular vehicle, such as the training methods, is important to this invention since it makes the monitoring system robust, reliable and accurate. The resulting systems are easy to implement at a low cost making them practical for automotive applications. The cost of the ultrasonic transducers, for example, is expected to be less than about $1 in quantities of one million per year and CMOS cameras, currently less than $5 each in similar quantities. Similarly, the implementation of the techniques of the above-referenced patents requires expensive microprocessors while the implementation with neural networks and similar trainable pattern recognition technologies permits the use of low cost microprocessors typically costing less than about $5 in quantities of one million per year.

The present invention is best implemented using sophisticated software that develops trainable pattern recognition algorithms such as neural networks and combination neural networks. Usually the data is preprocessed, as discussed below, using various feature extraction techniques and the results post-processed to improve system accuracy. A non-automotive example of such a pattern recognition system using neural networks on sonar signals is discussed in two papers by Gorman, R. P. and Sejnowski, T. J. "Analysis of Hidden Units in a Layered Network Trained to Classify Sonar Targets", Neural Networks, Vol. 1. pp. 75–89, 1988, and "Learned Classification of Sonar Targets Using a Massively Parallel Network", IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol. 36, No. 7, July 1988. Examples of feature extraction techniques can be found in U.S. Pat. No. 4,906,940 entitled "Process and Apparatus for the Automatic Detection and Extraction of Features in Images and Displays" to Green et al. Examples of other more advanced and efficient pattern recognition techniques can be found in U.S. Pat. No. 5,390,136 entitled "Artificial Neuron and Method of Using Same" and U.S. Pat. No. 5,517,667 entitled "Neural Network That Does Not Require Repetitive Training" to Wang, S. T. Other examples include U.S. Pat. No. 5,235,339 (Morrison et al.), U.S. Pat. No. 5,214,744 (Schweizer et al), U.S. Pat. No. 5,181,254 (Schweizer et al), and U.S. Pat. No. 4,881,270 (Knecht et al) All of the references herein are incorporated herein by reference.

4. Ultrasonics and Optics

Both laser and non-laser optical systems in general are good at determining the location of objects within the two dimensional plane of the image and a pulsed laser radar system in the scanning mode can determine the distance of each part of the image from the receiver by measuring the time of flight through range gating techniques. Distance can also be determined by using modulated electromagnetic radiation and measuring the phase difference between the transmitted and received waves. It is also possible to determine distance with the non-laser system by focusing, or stereographically if two spaced apart receivers are used and, in some cases, the mere location in the field of view can be used to estimate the position relative to the airbag, for example. Finally, a recently developed pulsed quantum well diode laser also provides inexpensive distance measurements as discussed in U.S. Pat. No. 6,324,453, which is incorporated herein by reference as if the entire contents were copied here.

Acoustic systems are additionally quite effective at distance measurements since the relatively low speed of sound permits simple electronic circuits to be designed and minimal microprocessor capability is required. If a coordinate system is used where the z-axis is from the transducer to the occupant, acoustics are good at measuring z dimensions while simple optical systems using a single CCD or CMOS arrays are good at measuring x and y dimensions. The combination of acoustics and optics, therefore, permits all three measurements to be made from one location with low cost components as discussed in commonly assigned U.S. Pat. Nos. 5,845,000 and 5,835,613 cross-referenced above.

One example of a system using these ideas is an optical system which floods the passenger seat with infrared light coupled with a lens and a receiver array, e.g., CCD or CMOS array, which receives and displays the reflected light and an analog to digital converter (ADC) which digitizes the output of the CCD or CMOS and feeds it to an Artificial Neural Network (ANN) or other pattern recognition system for analysis. This system uses an ultrasonic transmitter and receiver for measuring the distances to the objects located in the passenger seat. The receiving transducer feeds its data

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into an ADC and from there the converted data is directed into the ANN. The same ANN can be used for both systems thereby providing full three-dimensional data for the ANN to analyze. This system, using low cost components, will permit accurate identification and distance measurements not possible by either system acting alone. If a phased array system is added to the acoustic part of the system, the optical part can determine the location of the driver's ears, for example, and the phased array can direct a narrow beam to the location and determine the distance to the occupant's ears.

Although the use of ultrasound for distance measurement has many advantages, it also has some drawbacks. First, the speed of sound limits the rate at which the position of the occupant can be updated to approximately 10 milliseconds, which though sufficient for most cases, is marginal if the position of the occupant is to be tracked during a vehicle crash. Second, ultrasound waves are diffracted by changes in air density that can occur when the heater or air conditioner is operated or when there is a high-speed flow of air past the transducer. Third, the resolution of ultrasound is limited by its wavelength and by the transducers, which are high Q tuned devices. Typically, the resolution of ultrasound is on the order of about 2 to 3 inches. Finally, the fields from ultrasonic transducers are difficult to control so that reflections from unwanted objects or surfaces add noise to the data

Ultrasonics alone can be used in several configurations for monitoring the interior of a passenger compartment of an automobile as described in the above-referenced patents and patent applications and in particular in U.S. Pat. No. 5,943, 295 Using the teachings of this invention, the optimum number and location of the ultrasonic and/or optical transducers can be determined as part of the adaptation process for a particular vehicle model.

In the cases of the instant invention, as discussed in more detail below, regardless of the number of transducers used, a trained pattern recognition system, as defined above, is preferably used to identify and classify, and in some cases to locate, the illuminated object and its constituent parts.

5. Applications

The applications for this technology are numerous as described in the patents and patent applications listed above. However, the main focus of the instant invention is the process and resulting apparatus of adapting the system in the patents and patent applications referenced above and using combination neural networks for the detection of the presence of an occupied child seat in the rear facing position or an out-of-position occupant and the detection of an occupant in a normal seating position. The system is designed so that in the former two cases, deployment of the occupant protection apparatus (airbag) may be controlled and possibly suppressed, and in the latter case, it will be controlled and enabled.

One preferred implementation of a first generation occupant sensing system, which is adapted to various vehicle models using the teachings presented herein, is an ultrasonic occupant position sensor. This system uses a Combination Artificial Neural Network (CANN) to recognize patterns that it has been trained to identify as either airbag enable or airbag disable conditions. The pattern is obtained from four ultrasonic transducers that cover the front passenger seating area. This pattern consists of the ultrasonic echoes bouncing off of the objects in the passenger seat area. The signal from each of the four transducers consists of the electrical image of the return echoes, which is processed by the electronics. The electronic processing comprises amplification, logarithmic compression, rectification, and demodulation (band pass filtering), followed by discretization (sampling) and digitization of the signal. The only software processing required, before this signal can be fed into the combination artificial neural network, is normalization (i.e., mapping the input to numbers between 0 and 1). Although this is a fair amount of processing, the resulting signal is still considered "raw", because all information is treated equally.

OBJECTS AND SUMMARY OF THE INVENTION

In general, it is an object of the present invention to provide a new and improved system for identifying the presence, position and/or orientation of an object in a vehicle.

It is another broad object of the present invention to provide a system for accurately detecting the presence of an occupied rear-facing child seat in order to prevent an occupant protection apparatus, such as an airbag, from deploying, when the airbag would impact against the rear-facing child seat if deployed.

It is yet another broad object of the present invention to provide a system for accurately detecting the presence of an out-of-position occupant in order to prevent one or more deployable occupant protection apparatus such as airbags from deploying when the airbag(s) would impact against the head or chest of the occupant during its initial deployment phase causing injury or possible death to the occupant

This invention is a system designed to identify, locate and monitor occupants, including their parts, and other objects in the passenger compartment and in particular an occupied child seat in the rear facing position or an out-of-position occupant, by illuminating the contents of the vehicle with ultrasonic or electromagnetic radiation, for example, by transmitting radiation waves, as broadly defined above to include capacitors and electric or magnetic fields, from a wave generating apparatus into a space above the seat, and receiving radiation modified by passing through the space above the seat using two or more transducers properly located in the vehicle passenger compartment, in specific predetermined optimum locations. More particularly, this invention relates to a system including a plurality of transducers appropriately located and mounted and which analyze the received radiation from any object which modifies the waves or fields, or which analyze a change in the received radiation caused by the presence of the object (e.g., a change in the dielectric constant), in order to achieve an accuracy of recognition heretofore not possible. Outputs from the receivers are analyzed by appropriate computational means employing trained pattern recognition technologies, and in particular combination neural networks, to classify, identify and/or locate the contents, and/or determine the orientation of, for example, a rear facing child seat. In general, the information obtained by the identification and monitoring system is used to affect the operation of some other system, component or device in the vehicle and particularly the passenger and/or driver airbag systems, which may include a front airbag, a side airbag, a knee bolster, or combinations of the same. However, the information obtained can be used for controlling or affecting the operation of a multitude of other vehicle systems.

When the vehicle interior monitoring system in accordance with the invention is installed in the passenger compartment of an automotive vehicle equipped with a occupant protection apparatus, such as an inflatable airbag, and the vehicle is subjected to a crash of sufficient severity that the crash sensor has determined that the protection apparatus is

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to be deployed, the system has determined (usually prior to the deployment) whether a child placed in the child seat in the rear facing position is present and if so, a signal has been sent to the control circuitry that the airbag should be controlled and most likely disabled and not deployed in the crash. It must be understood though that instead of suppressing deployment, it is possible that the deployment may be controlled so that it might provide some meaningful protection for the occupied rear-facing child seat. The system developed using the teachings of this invention also determines the position of the vehicle occupant relative to the airbag and controls and possibly disables deployment of the airbag if the occupant is positioned so that he/she is likely to be injured by the deployment of the airbag. As before, the deployment is not necessarily disabled but may be controlled to provide protection for the out-of-position occupant

Principle objects and advantages of the methods in accordance with the invention are:

1. To provide a reliable system for recognizing the presence of a rear-facing child seat on a particular seat of a motor vehicle.
2. To provide a reliable system for recognizing the presence of a human being on a particular seat of a motor vehicle.
3. To provide a reliable system for determining the position, velocity or size of an occupant in a motor vehicle.
4. To provide a reliable system for determining in a timely manner that an occupant is out-of-position, or will become out-of-position, and likely to be injured by a deploying airbag.
5. To provide a system in which transducers are located within the passenger compartment at specific locations such that a high reliability of classification of objects and their position is obtained from the signals generated by the transducers.
6. To provide a system including a variety of transducers such as seatbelt payout sensors, seatbelt buckle sensors, seat position sensors, seatback position sensors, and weight sensors and which is adapted so as to constitute a highly reliable occupant presence and position system when used in combination with electromagnetic, ultrasonic or other radiation or field sensors.

Accordingly, a method for controlling an occupant protection device in a vehicle comprises the steps of acquiring data from at least one sensor relating to an occupant in a seat to be protected by the occupant protection device, classifying the type of occupant based on the acquired data, when the occupant is classified as an empty seat or a rear-facing child seat, disabling or adjusting deployment of the occupant protection device, otherwise classifying the size of the occupant based on the acquired data, determining the position of the occupant by means of one of a plurality of algorithms selected based on the classified size of the occupant using the acquired data, each of the algorithms being applicable for a specific size of occupant, and disabling or adjusting deployment of the occupant protection device when the determined position of the occupant is more likely to result in injury to the occupant if the occupant protection device were to deploy. The algorithms may be pattern recognition algorithms such as neural networks.

Acquisition of data may be from a plurality of sensors arranged in the vehicle, each providing data relating to the occupancy state of the seat. Possible sensors include a camera, an ultrasonic sensor, a capacitive sensor or other electromagnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor. Further sensors include an electromagnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, and a heartbeat sensor for sensing a heartbeat of the occupant.

Classification of the type of occupant and the size of the occupant may be performed by a combination neural network created from a plurality of data sets, each data set representing a different occupancy state of the seat and being formed from data from the at least one sensor while the seat is in that occupancy state.

A feedback loop may be used in which a previous determination of the position of the occupant is provided to the algorithm for determining a current position of the occupant.

Adjustment of deployment of the occupant protection device when the occupant is classified as an empty seat or a rear-facing child seat may entail a depowered deployment, an oriented deployment and/or a late deployment.

A gating function may be incorporated into the method whereby it is determined whether the acquired data is compatible with data for classification of the type or size of the occupant and when the acquired data is not compatible with the data for classification of the type or size of the occupant, the acquired data is rejected and new data is acquired.

Another method for controlling a component in a vehicle entails acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, determining an occupancy state of the seat based on the acquired data, periodically acquiring new data from the at least one sensor, for each time new data is acquired, determining the occupancy state of the seat based on the acquired new data and the determined occupancy state from a preceding time and controlling the component based on the determined occupancy state of the seat. This thus involves use of a feedback loop.

The determination of the occupancy state of the seat is performed using at least one pattern recognition algorithm such as a combination neural network.

Another method for controlling a component in a vehicle comprises the steps of acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, identifying the occupant based on the acquired data, determining the position of the occupant based on the acquired data, controlling the component based on at least one of the identification of the occupant and the determined position of the occupant, periodically acquiring new data from the at least one sensor, and for each time new data is acquired, identifying the occupant based on the acquired new data and an identification from a preceding time and determining the position of the occupant based on the acquired new data and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant. This also involves use of a feedback loop

Determination of the position of the occupant based on the acquired new data may entail considering a determination of the position of the occupant from the preceding time.

Identification of the occupant based on the acquired data may entail using data from a first subset of the plurality of sensors whereas the determination of the position of the

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occupant based on the acquired data may entail using data from a second subset of the plurality of sensors different than the first subset.

Identification of the occupant based on the acquired data and the determination of the position of the occupant based on the acquired data may be performed using pattern recognition algorithms such as a combination neural network.

Another method for controlling a component in a vehicle may comprise the steps of acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, identifying an occupant based on the acquired data, determining the position of the occupant based on the acquired data, controlling the component based on at least one of the identification of the occupant and the determined position of the occupant, periodically acquiring new data from the at least one sensor, and for each time new data is acquired, identifying an occupant based on the acquired new data and determining the position of the occupant based on the acquired new data and a determination of the position of the occupant from a preceding time and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant.

Another method for controlling a component in a vehicle comprises the steps of acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, identifying the occupant based on the acquired data, when the occupant is identified as a child seat, determining the orientation of the child seat based on the acquired data, determining the position of the child seat by means of one of a plurality of algorithms selected based on the determined orientation of the child seat, each of the algorithms being applicable for a specific orientation of a child seat, and controlling the component based on the determined position of the child seat. When the occupant is identified as other than a child seat, the method entails determining at least one of the size and position of the occupant and controlling the component based on the at least one of the size and position of the occupant.

In some of the implementations of the invention described above, a combination or combinational neural network is used. The particular combination neural network can be determined by a process in which a number of neural network modules are combined in a parallel and a serial manner and an optimization program can be utilized to determine the best combination of such neural networks to achieve the highest accuracy. Alternately, the optimization process can be undertaken manually in a trial and error manner. In this manner, the optimum combination of neural networks is selected to solve the particular pattern recognition and categorization objective desired.

These and other objects and advantages will become apparent from the following description of the preferred embodiments of the vehicle identification and monitoring system of this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings are illustrative of embodiments of the system developed or adapted using the teachings of this invention and are not meant to limit the scope of the invention as encompassed by the claims. In particular, the illustrations below are limited to the monitoring of the front passenger seat for the purpose of describing the system. Naturally, the invention applies as well to adapting the system to the other seating positions in the vehicle and particularly to the driver position.

FIG. **1** shows a seated-state detecting unit developed in accordance with the present invention and the connections between ultrasonic or electromagnetic sensors including wave and field sensors, a weight sensor, a reclining angle detecting sensor, a seat track position detecting sensor, a heartbeat sensor, a motion sensor, a neural network circuit, and an airbag system installed within a vehicle compartment;

FIG. **2** is a perspective view of a vehicle containing two adult occupants on the front seat with the vehicle shown in phantom illustrating one preferred location of the transducers placed according to the methods taught in this invention.

FIG. **3** is a view as in FIG. **2** with the passenger occupant replaced by a child in a forward facing child seat.

FIG. **4** is a view as in FIG. **2** with the passenger occupant replaced by a child in a rearward facing child seat.

FIG. **5** is a view as in FIG. **2** with the passenger occupant replaced by an infant in an infant seat.

FIG. **6** is a diagram illustrating the interaction of two ultrasonic sensors and how this interaction is used to locate a circle is space.

FIG. **7** is a view as in FIG. **2** with the occupants removed illustrating the location of two circles in space and how they intersect the volumes characteristic of a rear facing child seat and a larger occupant.

FIG. **8** illustrates a preferred mounting location of a three-transducer system.

FIG. **9** illustrates a preferred mounting location of a four-transducer system.

FIG. **10** is a plot showing the target volume discrimination for two transducers.

FIG. **11** illustrates a preferred mounting location of a eight-transducer system.

FIG. **12** is a schematic illustrating a combination neural network system.

FIG. **13** is a schematic illustration of a method in which the occupancy state of a seat of a vehicle is determined using a combination neural network in accordance with the invention.

FIG. **14** is a schematic illustration of a method in which the identification and position of the occupant is determined using a combination neural network in accordance with the invention.

FIG. **15** is a schematic illustration of a method in which the occupancy state of a seat of a vehicle is determined using a combination neural network in accordance with the invention in which bad data is prevented from being used to determine the occupancy state of the vehicle.

FIG. **16** is a schematic illustration of another method in which the occupancy state of a seat of a vehicle is determined, in particular, for the case when a child seat is present, using a combination neural network in accordance with the invention.

FIG. **17** is a schematic illustration of a method in which the occupancy state of a seat of a vehicle is determined using a combination neural network in accordance with the invention, in particular, an ensemble arrangement of neural networks.

FIG. **18** is a database of data sets for use in training of a neural network in accordance with the invention.

FIG. **19** is a categorization chart for use in a training set collection matrix in accordance with the invention.

FIGS. **20**, **21** and **22** are charts of infant seats, child seats and booster seats showing attributes of the seats and a designation of their use in the training database, validation database or independent database in and exemplifying embodiment of the invention.

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FIGS. 23A–23D show a chart showing different vehicle configurations for use in training of combination neural network in accordance with the invention.

FIGS. 24A–24H show a training set collection matrix for training a neural network in accordance with the invention.

FIG. 25 shows an independent test set collection matrix for testing a neural network in accordance with the invention.

FIG. 26 is a table of characteristics of the data sets used in the invention.

FIG. 27 is a table of the distribution of the main training subjects of the training data set.

FIG. 28 is a table of the distribution of the types of child seats in the training data set.

FIG. 29 is a table of the distribution of environmental conditions in the training data set.

FIG. 30 is a table of the distribution of the validation data set.

FIG. 31 is a table of the distribution of human subjects in the validation data set.

FIG. 32 is a table of the distribution of child seats in the validation data set.

FIG. 33 is a table of the distribution of environmental conditions in the validation data set.

FIG. 34 is a table of the inputs from ultrasonic transducers.

FIG. 35 is a table of the baseline network performance.

FIG. 36 is a table of the performance per occupancy subset.

FIG. 37 is a tale of the performance per environmental conditions subset.

FIG. 38 is a chart of four typical raw signals which are combined to constitute a vector.

FIG. 39 is a table of the results of the normalization study.

FIG. 40 is a table of the results of the low threshold filter study.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

System Adaptation involves the process by which the hardware configuration and the software algorithms are determined for a particular vehicle. Each vehicle model or platform will most likely have a different hardware configuration and different algorithms. Some of the various aspects that make up this process are as follows:

- The determination of the mounting location and aiming or orientation of the transducers.
- The determination of the transducer field angles or area or volume monitored
- The use of a combination neural network algorithm generating program such as available from International Scientific Research, Inc. to help generate the algorithms or other pattern recognition algorithm generation program.
- The process of the collection of data in the vehicle, for example, for neural network training purposes.
- The method of automatic movement of the vehicle seats etc. while data is collected
- The determination of the quantity of data to acquire and the setups needed to achieve a high system accuracy, typically several hundred thousand vectors or data sets.
- The collection of data in the presence of varying environmental conditions such as with thermal gradients.

- The photographing of each data setup.
- The makeup of the different databases and the use of typically three different databases.
- The method by which the data is biased to give higher probabilities for forward facing humans.
- The automatic recording of the vehicle setup including seat, seat back, headrest, window, visor, armrest etc. positions to help insure data integrity.
- The use of a daily setup to validate that the transducer configuration and calibration has not changed.
- The method by which bad data is culled from the database.
- The inclusion of the Fourier transforms and other pre-processors of the data in the algorithm generation process.
- The use of multiple algorithm levels, for example, for categorization and position.
- The use of multiple algorithms in parallel.
- The use of post processing filters and the particularities of these filters.
- The addition of fuzzy logic or other human intelligence based rules.
- The method by which data errors are corrected using, for example, a neural network.
- The use of a neural network generation program as the pattern recognition algorithm generating system.
- The use of back propagation neural networks from training.
- The use of vector or data normalization.
- The use of feature extraction techniques, for ultrasonic systems for example, including:
  - The number of data points prior to a peak.
  - The normalization factor.
  - The total number of peaks.
  - The vector or data set mean or variance.
- The use of feature extraction techniques, for optics systems for example, including:
  - Motion.
  - Edge detection.
  - Feature detection such as the eyes, head etc.
  - Texture detection.
  - Recognizing specific features of the vehicle.
  - Line subtraction—i.e. subtracting one line of pixels from the adjacent line.
- The use of other computational intelligence systems such as the genetic algorithms
- The use the data screening techniques.
- The techniques used to develop a stable networks including the concepts of old and new networks.
- The time spent or the number of iterations spent in, and method of, arriving at stable networks.
- The technique where a small amount of data is collected first such as 16 sheets followed by a complete data collection sequence.
- The use of a cellular neural network for high speed data collection and analysis when electromagnetic transducers are used.
- The use of a support vector machine.

The process of adapting the system to the vehicle begins with a survey of the vehicle model. Any existing sensors, such as seat position sensors, seat back sensors, etc., are immediate candidates for inclusion into the system Input from the customer will determine what types of sensors

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would be acceptable for the final system. These sensors can include: seat structure mounted weight sensors, pad type weight sensors, pressure type weight sensors (e.g. bladders), seat fore and aft position sensors, seat-mounted capacitance, electric field or antenna sensors, seat vertical position sensors, seat angular position sensors, seat back position sensors, headrest position sensors, ultrasonic occupant sensors, optical occupant sensors, capacitive sensors, electric field sensors, inductive sensors, radar sensors, vehicle velocity and acceleration sensors, brake pressure, seatbelt force, payout and buckle sensors, accelerometers, gyroscopes, chemical etc. A candidate array of sensors is then chosen and mounted onto the vehicle.

The vehicle is also instrumented so that data input by humans is minimized. Thus, the positions of the various components in the vehicle such as the seats, windows, sun visor, armrest, etc. are automatically recorded where possible. Also, the position of the occupant while data is being taken is also recorded through a variety of techniques such as direct ultrasonic ranging sensors, optical ranging sensors, radar ranging sensors, optical tracking sensors etc. Special cameras are also installed to take one or more pictures of the setup to correspond to each vector of data collected or at some other appropriate frequency. Herein, a vector is used to represent a set of data collected at a particular epoch or representative of the occupant or environment of vehicle at a particular point in time

A standard set of vehicle setups is chosen for initial trial data collection purposes. Typically, the initial trial will consist of between 20,000 and 100,000 setups, although this range is not intended to limit the invention.

Initial digital data collection now proceeds for the trial setup matrix. The data is collected from the transducers, digitized and combined to form to a vector of input data for analysis by a pattern recognition system such as a neural network program or combination neural network program. This analysis should yield a training accuracy of nearly 100%. If this is not achieved, then additional sensors are added to the system or the configuration changed and the data collection and analysis repeated.

In addition to a variety of seating states for objects in the passenger compartment, the trial database will also include environmental effects such as thermal gradients caused by heat lamps and the operation of the air conditioner and heater, or where appropriate lighting variations or other environmental variations that might affect particular transducer types. A sample of such a matrix is presented in FIGS. 24A–24H, with some of the variables and objects used in the matrix being designated or described in FIGS. 18–23D. After the neural network has been trained on the trial database, the trial database will be scanned for vectors that yield erroneous results (which would likely be considered bad data) A study of those vectors along with vectors from associated in time cases are compared with the photographs to determine whether there is erroneous data present. If so, an attempt is made to determine the cause of the erroneous data. If the cause can be found, for example if a voltage spike on the power line corrupted the data, then the vector will be removed from the database and an attempt is made to correct the data collection process so as to remove such disturbances.

At this time, some of the sensors may be eliminated from the sensor matrix. This can be determined during the neural network analysis, for example, by selectively eliminating sensor data from the analysis to see what the effect if any results. Caution should be exercised here, however, since once the sensors have been initially installed in the vehicle, it requires little additional expense to use all of the installed sensors in future data collection and analysis.

The neural network that has been developed in this first phase can be used during the data collection in the next phases as an instantaneous check on the integrity of the new vectors being collected. Occasionally, a voltage spike or other environmental disturbance will momentarily effect the data from some transducers. It is important to capture this event to first eliminate that data from the database and second to isolate the cause of the erroneous data.

The next set of data to be collected when neural networks are used, for example, is the training database. This will usually be the largest database initially collected and will cover such setups as listed, for example, in FIGS. 24A–24H. The training database, which may contain 500,000 or more vectors, will be used to begin training of the neural network or other pattern recognition system. In the foregoing description, a neural network will be used for exemplary purposes with the understanding that the invention is not limited to neural networks and that a similar process exists for other pattern recognition systems. This invention is largely concerned with the use of pattern recognition systems for vehicle internal monitoring. The best mode is to use trained pattern recognition systems such as neural networks. While this is taking place additional data will be collected according to FIGS. 20–22 and 25 of the independent and validation databases. The training database is usually selected so that it uniformly covers all seated states that are known to be likely to occur in the vehicle. The independent database may be similar in makeup to the training database or it may evolve to more closely conform to the occupancy state distribution of the validation database. During the neural network training, the independent database is used to check the accuracy of the neural network and to reject a candidate neural network design if its accuracy, measured against the independent database, is less than that of a previous network architecture.

Although the independent database is not actually used in the training of the neural network, nevertheless, it has been found that it significantly influences the network structure or architecture. Therefore, a third database, the validation or real world database, is used as a final accuracy check of the chosen system. It is the accuracy against this validation database that is considered to be the system accuracy. The validation database is usually composed of vectors taken from setups which closely correlate with vehicle occupancy in real cars on the roadway. Initially the training database is usually the largest of the three databases. As time and resources permit the independent database, which perhaps starts out with 100,000 vectors, will continue to grow until it becomes approximately the same size or even larger than the training database. The validation database, on the other hand, will typically start out with as few as 50,000 vectors. However, as the hardware configuration is frozen, the validation database will continuously grow until, in some cases, it actually becomes larger than the training database. This is because near the end of the program, vehicles will be operating on highways and data will be collected in real world situations. If in the real world tests, system failures are discovered this can lead to additional data being taken for both the training and independent databases as well as the validation database.

Once a neural network has been trained using all of the available data from all of the transducers, it is expected that the accuracy of the network will be very close to 100%. It is usually not practical to use all of the transducers that have been used in the training of the system for final installation

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